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Canada Topographical Survey

DEPARTMENT OF THE INTERIOR, CANADA

HON. CHARLES STEWART, Minister

W. W. CORY, Deputy Minister

TOPOGRAPHICAL SURVEY OF CANADA

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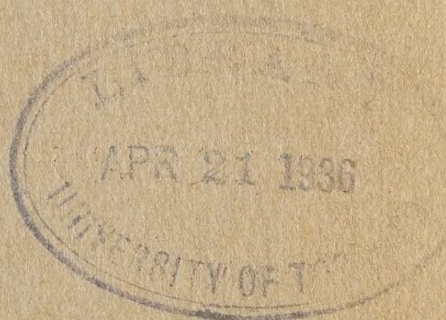
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BULLETIN No. 56

PHOTOGRAPHIC SURVEYING

BY

M. P. BRIDGLAND, D.L.S.



OTTAWA

F. A. ACLAND

PRINTER TO THE KING'S MOST EXCELLENT MAJESTY

1924







*Frontispiece*

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# PHOTOGRAPHIC SURVEYING

BY

M. P. BRIDGLAND, D.L.S.

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## 1. Introduction

Although photographic methods of surveying are recognized generally as affording the most accurate and economical means of mapping certain classes of country and have long been firmly established in practice, literature dealing with this class of surveys is scarce, and in most of the accepted textbooks on surveying, if it is mentioned at all, the authors devote but limited space to it; the existence of the photographic system is little more than recognized or at best a brief introduction to the subject is offered. Even then, there seems to be some difference of opinion as to its utility, probably because the writers have had little or no practical experience with photographic methods of surveying and are not personally familiar with the conditions, physical or climatic, under which much of the work must be carried on.

While an extensive knowledge of the principles of descriptive geometry, perspective drawing and optics is not an essential qualification in order that a surveyor may successfully carry on photographic surveys, there is no doubt that such knowledge is of great value to one desirous of rapidly acquiring an intelligent grasp of the subject and of the methods employed. Moreover, he will meet with many problems in the solution of which the application of these principles will not only prove of advantage in the prosecution of the surveys, but will also tend to increase his own interest in the work and the pleasure he derives from it.

In this pamphlet, no attempt has been made to deal with the subject of photographic surveying from a theoretical standpoint, the object being to present it in a practical manner, so that the principles involved may be readily grasped by anyone familiar with surveying in general. The methods employed in the field and the difficulties encountered are briefly reviewed, and descriptions are given of the instruments and constructions ordinarily used in the office.

The writer wishes to acknowledge his extreme indebtedness to Dr. E. Deville, whose book entitled *Photographic Surveying* was published in 1895. This volume, which unfortunately has been long out of print, deals most ably with the subject from both a theoretical and practical standpoint. From this book the writer has derived the greater part of his knowledge of photographic surveying, and he feels that no apology is necessary for quoting many passages from it verbatim or nearly so.

## 2. Historical Notes

In phototopographical surveys, the photographs serve as perspectives from which the maps are constructed using the inverse principles of perspective, and on this account the system is often referred to as iconometry. The principles involved were first suggested by J. H. Lambert, of Zurich, in 1759, but no

effort to apply them practically was made until 1791-3, when Beautemps-Beaupré made the first attempt, using a series of freehand sketches of the coastal regions of Tasmania and Santa Cruz island. Although himself convinced of the feasibility of the system, he failed to convince others, probably on account of the difficulty of making freehand drawings sufficiently accurate to give good results, and so the methods he suggested were almost forgotten.

In 1839, Arago called attention to the possibilities of utilizing photography, and in 1849 Captain Leblanc made an attempt to apply it to French military surveys. All early attempts were much hampered by the slowness and uncertainty of the early photographic processes, by the imperfections of the lenses and by the heavy and cumbersome apparatus required. In 1856, Col. A. Laussedat, who was really the founder of photographic surveying, began a study of the subject, using at first a "camera lucida." This consisted of a four-sided prism, mounted over a drawing-board, which, by a double reflection of the rays through an angle of  $90^\circ$ , enabled the operator to see the image as though coming from the board and to make a freehand sketch of it on the paper placed thereon. For some years he continued this work, improving the instruments and elaborating the methods, and, when a suitable lens was obtained, substituted photographs in place of freehand drawings. In 1859, he felt justified in announcing his success to the Academy of Sciences in Paris, and, after a careful and critical examination, a favourable report was given and photographic surveying passed beyond the experimental stage and became a recognized science. A still further impetus was given to its development when dry plates were placed on the market about 1873, and later improvements in lenses and plates, resulting in more perfect images and better negatives, have added much to the value of photography as applied to practical surveying.

Since its introduction by Col. Laussedat, the subject has received the attention of many noted scientists in other countries, and many extensive surveys have been made, not only in European countries, but also in many other parts of the world comparatively unknown at that time. For a complete account of the early history of its development, the reader is referred to Mr. J. A. Flemer's interesting book entitled *Photographic Methods and Instruments*.

The introduction of photographic surveying into Canada was due to Dr. E. Deville, Surveyor General of Dominion Lands. He was quick to realize its value for mapping the extensive mountain regions of Western Canada, and, being a man of high scientific attainments, he designed instruments which he considered specially suitable for the requirements of the rough and rugged country in which they would have to be used. These instruments are still in use, almost in their original form, though minor alterations have been made and modern lenses have replaced those originally used in the cameras. In 1886, Mr. J. J. McArthur, D.L.S., with a small party, was sent out to commence a topographic survey of part of the Rocky mountains adjacent to the Canadian Pacific railway. This work was continued for about seven years, and, although largely experimental in its early stages, was so successful that Mr. McArthur was able to map an area of about two thousand square miles, using a scale of  $1/20,000$  and a contour interval of 100 feet. Since that time many other surveys of a like nature, though plotted on different scales and with varying contour

intervals, have been made in Canada, not only by the Topographical Survey of Canada but also by other Government departments, and more recently by the British Columbia Government.

### 3. Instruments

In designing instruments for the work, two different lines of construction have been followed. In the first, which has been used by most European designers, the camera and transit have been combined in one instrument which consists of either a camera revolving on a graduated vertical circle and carrying a small telescope mounted eccentrically, or a transit with a small camera mounted either between the standards or above the axis. A combination of the two instruments presents many difficulties, and great ingenuity has been displayed in the many different forms that have been designed. Unfortunately, all these instruments are somewhat complicated, require careful adjustment and are not built to stand the unavoidable abuse due to the difficulties of transportation in very rough country. The second method of construction is to have the camera and transit entirely separate. This method, which has been followed by Canadian and American designers, obviously simplifies the problem very much and permits the construction of the instruments in a very simple form without any complicated adjustments, so that there is little danger of injury during transportation.

The following description of the instruments used on Canadian surveys and their adjustments has been taken from *Photographic Surveying*. Although some alterations have been made in the instruments used by other branches, the principles involved are the same, and the reader will have little difficulty in understanding the forms in use.

The transit is one of the ordinary patterns used by surveyors and is shown in fig. 1. It has three-inch circles and reads to minutes. The tripod is a short one, specially designed for mountain work. It is three feet four inches long and has sliding legs, the joint being perfectly stiff. The surveyor observes either in a sitting or kneeling position. For the purpose of packing, the head of the tripod is taken off and put in the transit box; when folded, the legs are twenty inches long and placed under the box of the transit as shown in frontispiece. The heavy parts of the instrument are made of aluminium; the whole, including tripod and case, and also the camera base, weighs fourteen pounds and eight ounces.

The camera is shown in figs. 2 and 3; fig. 4 represents sections of the instrument. The camera proper is a rectangular metal box  $AB$ , open at one end. It carries the lens  $L$  and two sets of cross levels  $CC$ , which are read through openings in the outer mahogany box. The metal box is supported by wooden blocks and by a frame  $FF$  held in position by two bolts  $DD$ . The plate-holder is made for single plates; it is inserted in a carrier  $EE$ , which can be moved forward and backward by means of the screw  $G$ . A folding shade  $HH$ , hooked in front of the camera, and diaphragms  $KK$ , inside of the metal box, intercept all light which does not contribute to the formation of the image on the photographic plate. The camera rests on a triangular base with foot-screws, identical with the base of the transit, so that both may fit on the same tripod. It may be set up with the longer side either horizontal or vertical.

The construction of the camera and the case in which it is carried is further illustrated in fig. 5. The upper part of the diagram shows the leather carrying-case, with the sunshade fastened inside the cover, containing a tin box and twelve plate-holders. Below, from left to right, there is shown the back which fits on the outer case, the camera base, the inner metal box with the lens and levels attached and the outer wooden case.

Having set up the camera on the tripod, the plate-holder carrier  $E$  is moved back as far as it will go by turning the screw  $G$ ; the plate-holder is inserted through the opening  $M$ , the slide is withdrawn, and the carrier moved forward by the screw  $G$  until the plate is in contact with the back of the metal box. In order to secure perfect contact, the carrier has a certain amount of free motion. The camera must now be turned in the proper direction; the field embraced by the plate is indicated by lines drawn on the outside of the mahogany box. The camera is then carefully levelled, the exposure given, and the plate-holder withdrawn by repeating the same operations in inverse order.

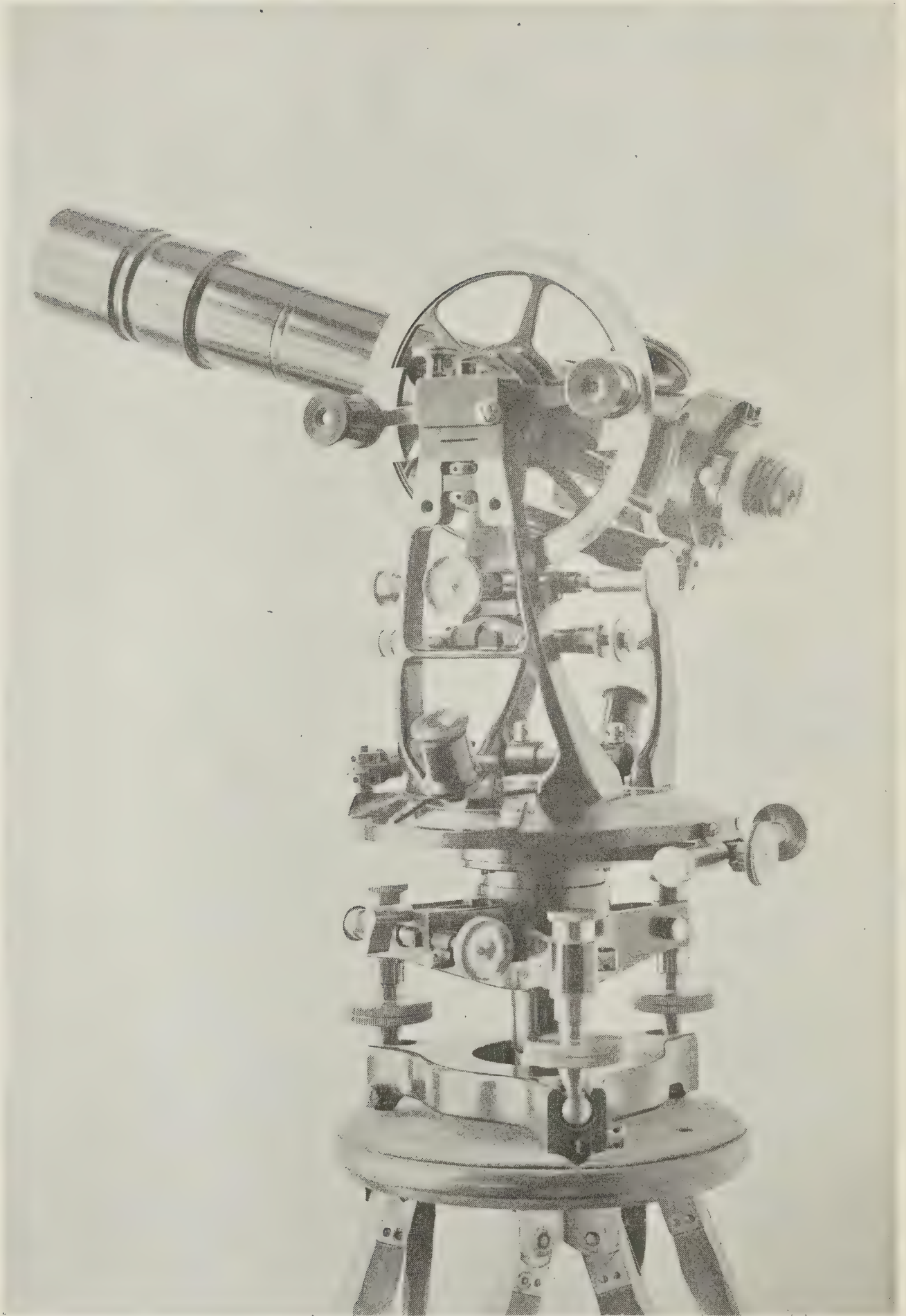


FIG. 1.—Transit Theodolite



FIG. 2.—Camera of the Topographical Survey of Canada (horizontal position)

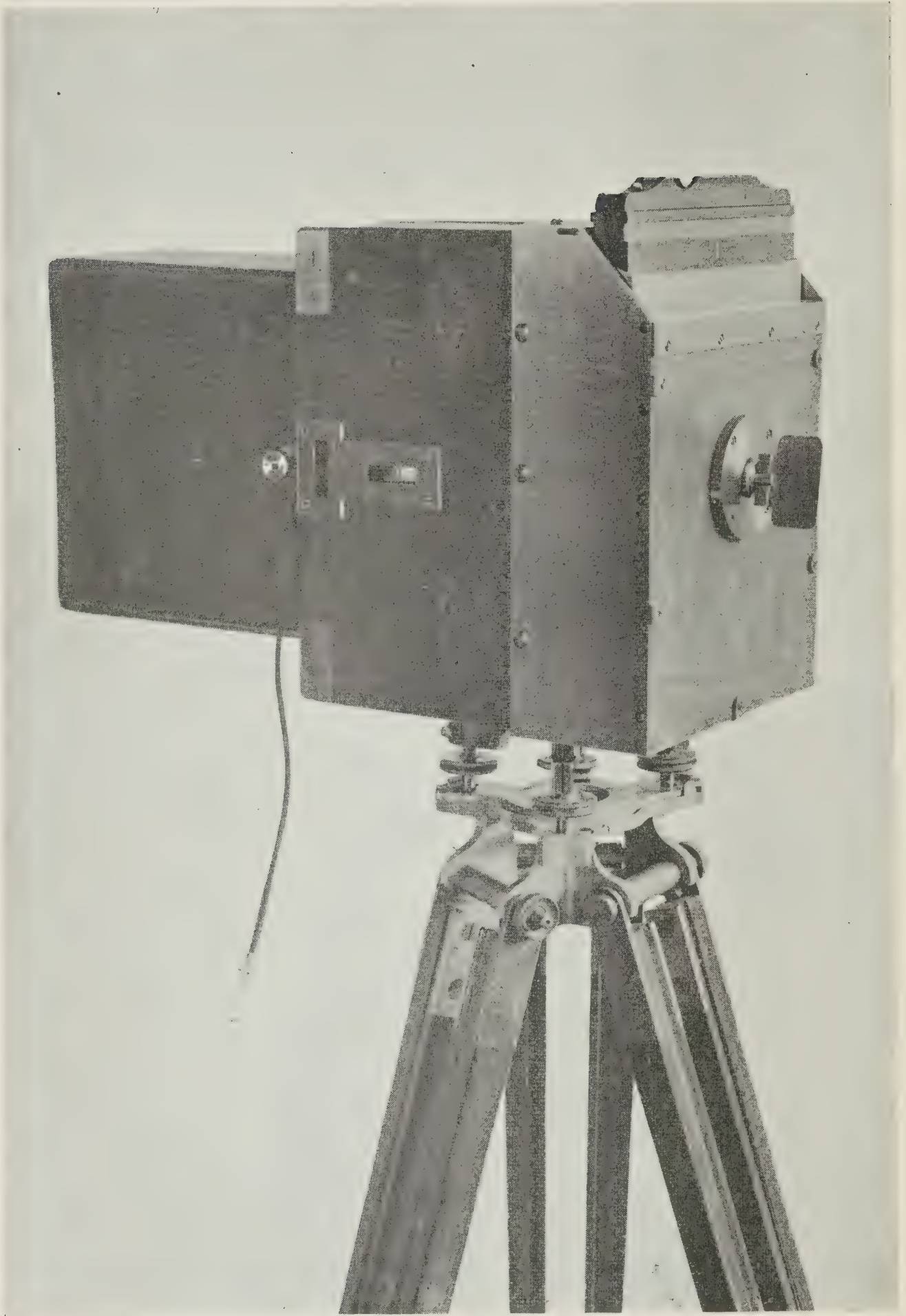


FIG. 3.—Camera of the Topographical Survey of Canada (vertical position)

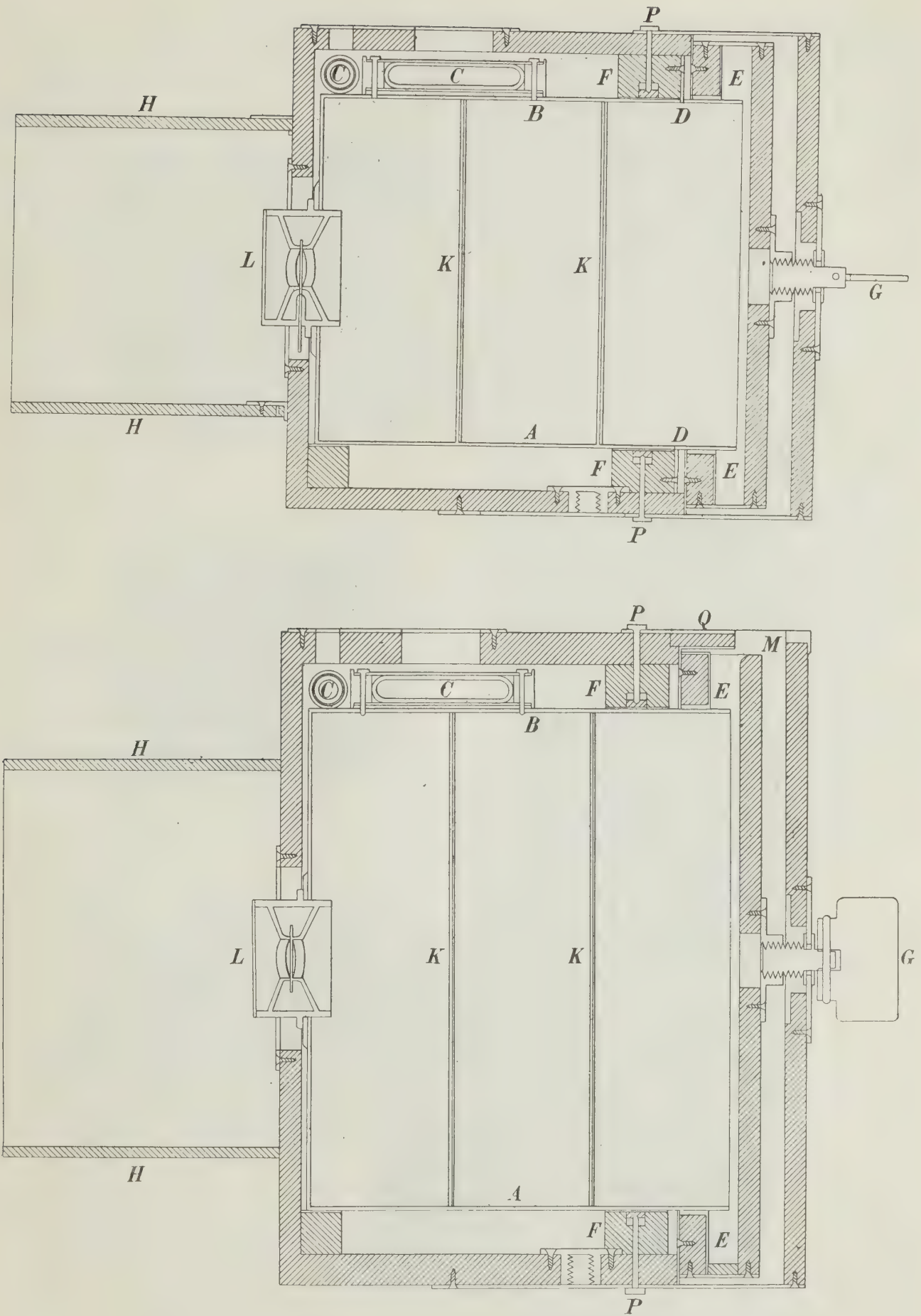


FIG. 4.—Cross sections of cameras

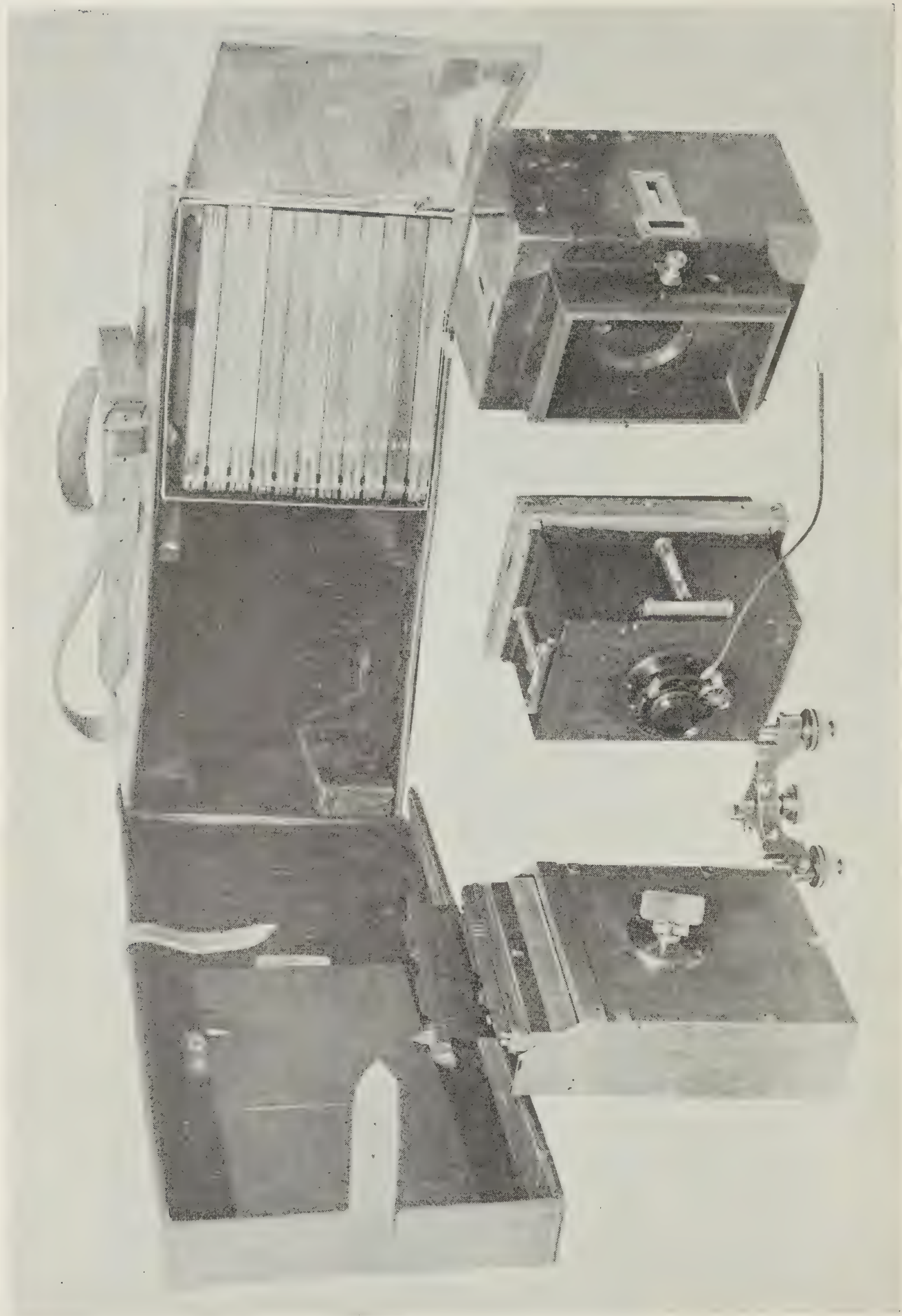


FIG. 5

The levels are rigidly fixed to the camera without any means of adjustment. They are, however, very nearly adjusted by the maker. For this purpose, he takes out the metal box and places it on a piece of plate glass which has been levelled like an artificial horizon. By filing one end or the other of the levels' outer case, he brings each bubble very nearly in the middle of its tube. These tubes bear continuous graduations as illustrated in fig. 6.

Accompanying the camera is a piece of plate glass,  $\frac{1}{4}$  inch thick and 11 inches long, which can be inserted in the carrier instead of the plate-holder. The end of the glass, which projects outside of the camera, is coated on the back with a varnish of gum guaiacum dissolved in alcohol to which some lamp black has been added. This varnish has very nearly the same refractive index as glass, and stops all reflections from the back of the plate glass.



FIG. 6

The first thing to be done when the camera is received from the maker is to ascertain the exact readings of the levels when the back of the metal box, on which the photographic plate is pressed, is vertical. To do this, the bolts  $P$  (fig. 4), next to the opening  $M$ , are unscrewed and removed;  $Q$  may then slide backwards and be taken out. The piece of plate glass is now inserted in the carrier  $E$ , and pressed in contact with the metal box. The camera is placed on its tripod and levelled.

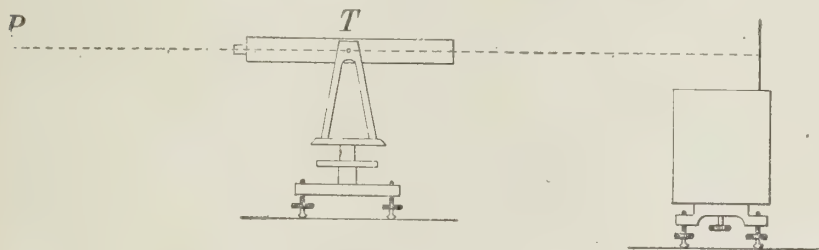


FIG. 7

Immediately in front and at the same height, a transit  $T$ , fig. 7, is set up, and after carefully adjusting it, a distant point  $P$  is selected on the same level as the transit and camera. The intersection of the threads of the telescope is brought to coincide with  $P$ , and the telescope is clamped to the vertical circle. Turning it around the vertical axis, the image of  $P$  reflected by the plate glass should appear upon the intersection of the telescope's threads. If it does, the face of the plate glass is vertical and the position of the bubble in the level tube is the correct one for adjusting the instrument. If it does not, the camera must be inclined forward or backward by means of the foot-screws until coincidence is established. The bubble of the level may or may not be now in the middle of the tube, but its position, whatever it is, is the correct one for adjusting the camera. The divisions of the graduation between which the bubble is comprised are therefore noted, and whenever the camera is to be levelled, it must be remembered that the bubble is to be brought between these two same divisions.

This determination is made for the two positions of the camera, horizontal and vertical.

The next step is to fix the place of the principal point on the photographic plate, and to measure the distance line or focal length.

Select a station so that a number of distinct and well defined distant points may be found on the horizon line. The view may be, for instance, the distant shore of a lake, a large building, or rows of buildings. Set up the tripod and adjust the transit. Find two points  $E$  and  $F$  on the horizon line, or with a zenith distance of  $90^\circ$ , so that they both come within the field of the camera, when set horizontal, and near the edges of the plate. Measure the angle  $\omega$  between them. Find two other points  $G$  and  $H$ , also on the horizon line, and such a distance apart that they both come within the field of the camera when set vertical. Now, replace the transit by the camera in the horizontal position, turn it so that it takes in  $E$  and  $F$ , level carefully and expose a plate.

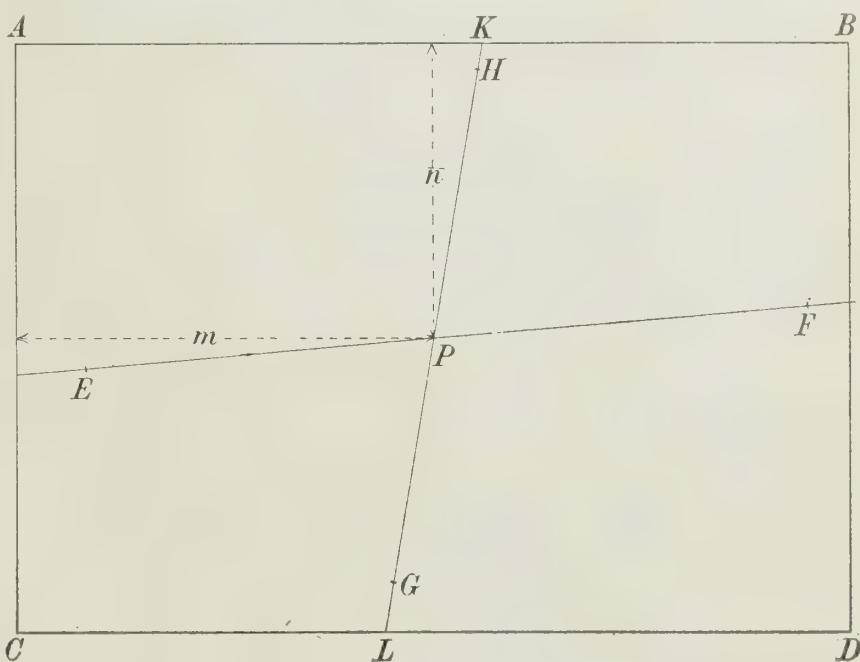


FIG. 8

Set the camera in the vertical position, turn it so that it takes in  $G$  and  $H$ , level carefully and expose another plate. The first plate, after development, shows the two points  $E$  and  $F$ , on a line very nearly parallel to the edges  $AB$  and  $CD$ , fig. 8, of the metal box. The principal point is of course on this line. Cut the line through the film with a fine needle point.



It is now necessary to find the correct readings of the transverse levels, when the horizon and principal lines pass exactly through the notches of the metal box.

Set up the camera again in front of the same distant view as before, but in adjusting it, bring the bubble of the transverse level near one end of the tube; note the reading of the graduation and expose a plate. When developed, it will give a horizon line  $\bar{EF}$  (fig. 11), cutting the border of the negative in  $A$  and  $B$ , at some distance from the notches  $O$  and  $Q$ . Now change the adjustment of the camera by bringing the bubble of the transverse level to the other end of the tube, note the reading of the level and expose another plate. This one gives another horizon line  $E'F'$  cutting the border of the negative in  $C$  and  $D$ .

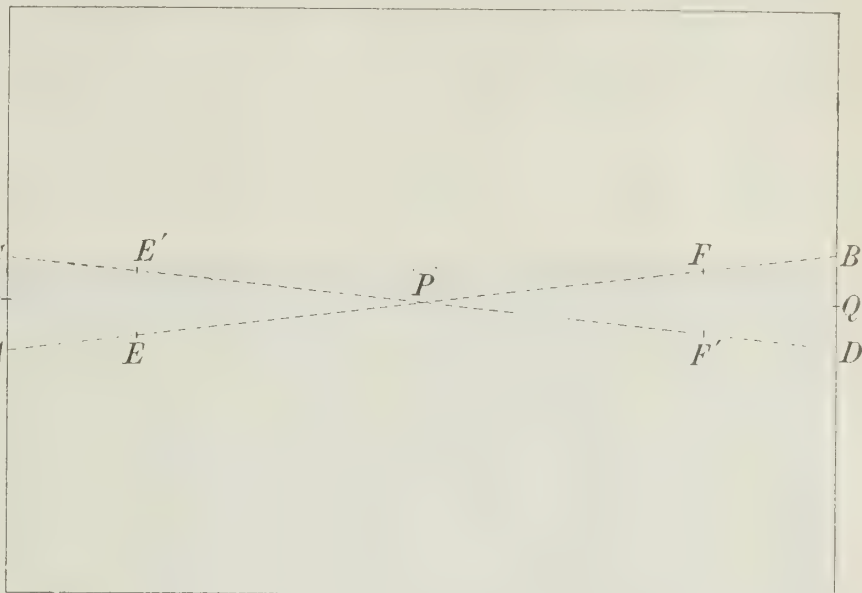


FIG. 11

After measuring  $CO$  and  $OA$  or  $BQ$  and  $QD$ , a simple proportion gives the reading of the level which shall bring the horizon line through the two notches  $O$  and  $Q$ .

The correct reading of the other transverse level is found by the same method, with the camera in the vertical position.

All these operations must be executed with great care and precision, and with the help of a microscope of moderate power.

It has been assumed that the levels were placed very nearly in correct adjustment by the maker. If found too much out, they must, of course, first be approximately adjusted by setting the metal box on a well levelled plane. For this purpose, the plate glass supplied is set on the camera base and levelled like an artificial horizon.

The lens now in use is a Zeiss Tessar Series III having a focal length of about 164 millimeters, and it is used along with a yellow screen known as a Wratten and Wainwright "G" filter. As the focal length of the lens is greater than the side of the plate,  $Rr$ ,  $Rr'$ ,  $Tt$  and  $Tt'$  (fig. 10) cannot be made equal to  $f/2$ , but a smaller fraction of the focal length,  $f/3$  or  $f/4$ , may be used to advantage for checking the size of the enlargements.

In its horizontal position the camera has a field of about  $51^\circ$  and in the vertical position a field of about  $37^\circ$ , the extent in either position being shown by the lines ruled on the box. Consequently it will have a dip of approximately  $18^\circ$  or  $26^\circ$  accordingly as it is used horizontally or vertically.

The camera is carried in a leather case fitted with shoulder straps, and designed to hold it, the sunshade and twelve plate-holders (fig. 5). The case, which is made of heavy leather, is not only useful for carrying the camera but is a great protection to the instrument when it has to be transported by packhorses or other means. The total weight of the case with the camera and twelve loaded plate-holders is about twenty pounds.

When setting up the tripod, a canvas bag is suspended between the legs and filled with stones, and then the legs and bag are blocked with more stones, so that the instrument may be rigid in any wind.

After the camera has been adjusted and marked as previously described, it is frequently necessary to check the positions of the levels and of the horizon and principal lines. As long as these lines pass through the notches  $HH$  and  $VV$  (fig. 12) when the bubbles are in their proper positions, thus affording an accurate means of transferring the lines from the test views to others, no adjustment is necessary. These conditions must hold for the camera in both its horizontal and vertical positions. If the lines do not pass through the notches, the levels must be readjusted as before. As the camera cannot always be handled very carefully during transportation, the positions of the two longitudinal bubbles, by means of which the plates are placed in a vertical plane,

must be carefully determined. Usually this is done at the beginning and end of the season, unless there is some reason to suspect a change of levels, in which case other tests should be made. It is also of advantage to make measurements, by which the focal length of the lens may be computed, even though using the same lens from year to year. This means little extra work and affords an independent method of checking the focal length of the enlargements used in plotting, as the contraction or expansion may vary in different lots of paper.

On account of the importance of the level adjustments and the necessity of frequent tests, the following full description is given of a method which has

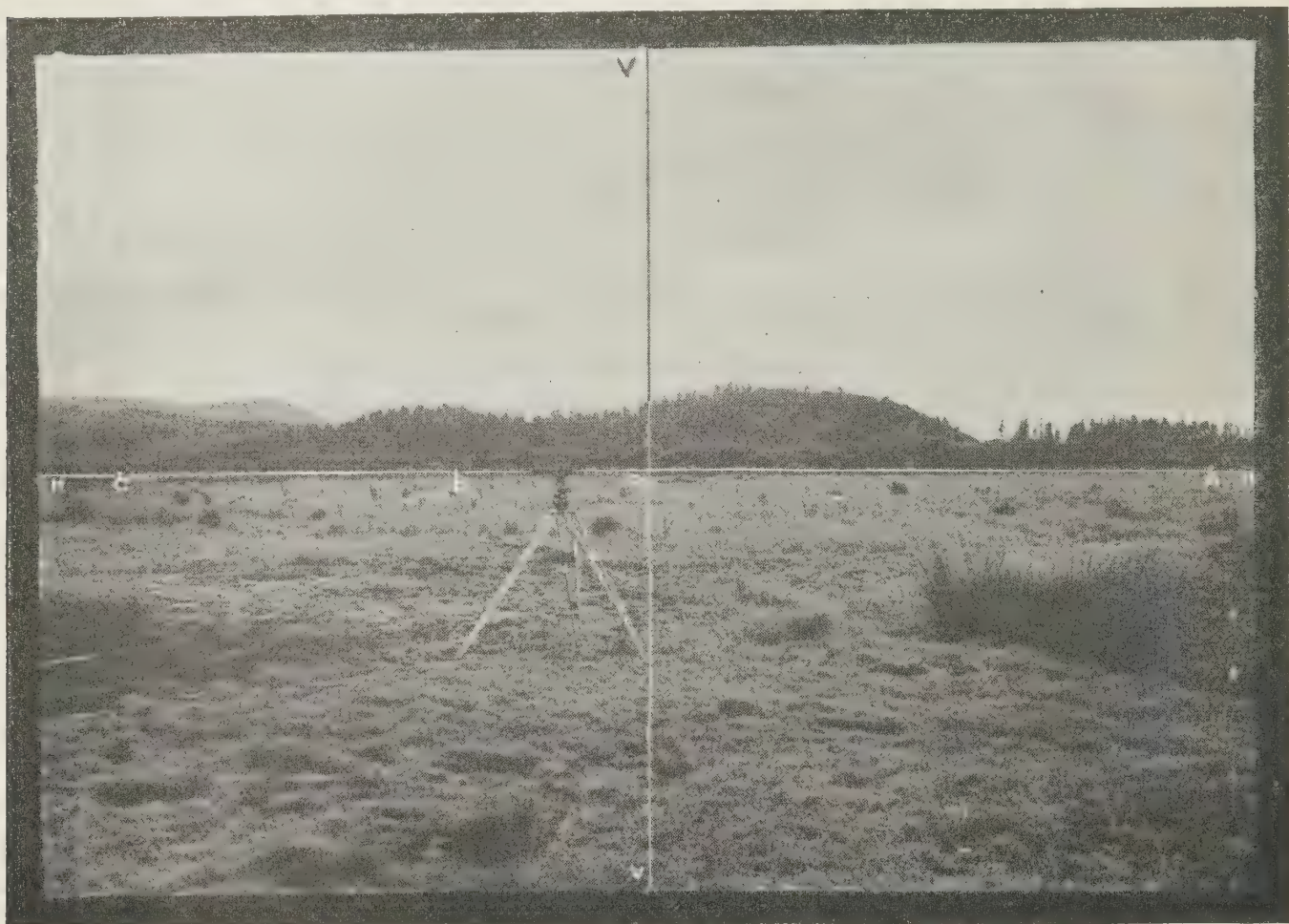


FIG. 12

been found simple and satisfactory for use in the field. This method is almost identical with that given by Dr. Deville, except that targets placed in proper positions are used instead of suitable objects already on the ground.

A place, usually a level meadow or a small valley, is selected, where several points of about the same elevation may be found. The camera is set up in a horizontal position and a level or transit placed a short distance away, so that the telescope of the latter is on the same level as the centre of the lens. Fig. 12 shows the transit placed in position. Then, some distance away, three targets, *A*, *B* and *C*, are placed on the same level and in such position that the two outside ones, *A* and *C*, will be just inside the field of the camera when horizontal, and *A* and *B* just inside the field when in the vertical position. The mirror, previously described, is then inserted and screwed up firmly against the inside case in the exact position occupied by the plate. The camera is turned until the reflection of one of the signals can be seen through the telescope, and it is then tilted forward or backward by means of the foot-screws until the horizontal hair of the telescope bisects the image of the target, the transverse level being kept in its centre position throughout. The mirror is then in a vertical plane, and the position of the bubble, parallel to the axis of the camera, is carefully noted. The mirror is removed, and, with the camera very carefully levelled,

one or more views are taken showing the transit and the three signals. After this the camera is set up in its vertical position and the mirror replaced. By shortening the legs of the tripod, the camera is lowered until the mirror shows above it when viewed through the telescope, and the position of the other bubble when the plate is vertical is found as before. When this is completed, the mirror is removed and the camera raised until the lens is again level with the telescope, and other plates are exposed in the vertical position showing the signals *A* and *B*.

For the determination of the focal length, the transit is then moved to the position occupied by the camera, and the angles subtended by the three signals are carefully read.

In making use of this information, the plate itself may be taken or the plotting enlargements. In either case the procedure is practically the same, but it is easier to work on the enlargements and that is really of more vital importance to the topographer than the negative. If several enlargements are used, they will give practically the focal length for use in plotting, as the contraction is not likely to vary much with the same lot of paper. This, however, cannot be taken for granted, and the dimensions of the enlargements must be carefully watched.

It is now necessary to determine the horizon and principal lines. On one of the horizontal views, draw carefully a fine line through the centres of the targets *A*, *B* and *C* (fig. 12) and then do the same on one of the vertical views. These lines represent the horizon lines for their respective views. Take the horizontal view, and, by means of the notches *VV*, transfer the line from the vertical view and find *P*, the intersection of the two lines. This is the principal point of the view. Through *P* draw a line *VV* perpendicular to the horizon line. This represents the principal line of the view, and, if all levels are in proper adjustment, should coincide with the vertical line as transferred from the second, though this condition is by no means necessary. The vertical view is then treated in a similar way.

To determine the focal length, the distance from the signals *A* and *C* to the principal point *P* must be very carefully measured. The focal length is then found as before.

Determinations of the focal length should be made for both positions of the camera, as the contraction of the paper in different directions may vary.

The surveying cameras of the Topographical Survey of Canada are put into adjustment at its Surveys Laboratory each season before being sent into the field. The adjustments described above can be quickly and accurately made with the aid of the optical apparatus of the laboratory. A description of this apparatus and the method followed in testing and adjusting surveying cameras will be found in Bulletin 48, *The Adjustment and Testing of Transit Theodolites, Levels and Surveying Cameras at the Laboratory of the Dominion Lands Surveys*.

While the laboratory ensures that the cameras are sent out into the field in good adjustment, it is still necessary that the surveyor be able to make the field tests here described, if for any reason he wishes to check the adjustments of his camera during a survey.

#### 4. Photography

In touching upon the subject of photography it would be difficult to improve upon the following introductory remarks from Dr. Deville's book:—

For surveying purposes, photographs must be clear and full of detail; the points to be plotted must be well defined and easily recognized. Just at the start, a serious difficulty is met with: distant points, which are those wanted by the surveyor, are always more or less indistinct in a landscape, the distance merging into a uniform tint by the effect of what is known as "aerial perspective." This effect is due to the light diffused by the mass of air between the observer and the distant point; the greater the distance, and consequently the greater the mass of intervening air, the more light is diffused and the more indistinct the distance becomes. From the artist's point of view, aerial perspective is necessary to give the impression of distance, but to the surveyor it is more objectionable.

The light diffused by the atmosphere is that which it has previously absorbed, and consists mainly of rays of shorter wave-lengths, which, although not very luminous, have the strongest actinic power. It thus happens that aerial perspective is very much exaggerated when translated by photography, the strong effect of the light emitted by the blue haze, through which the distance is seen, completely blurring on the plate the details of the image, so much so, that the photograph becomes almost useless for surveying. Several causes contribute to the same result, such as the presence of smoke in the air, dust raised by wind, etc.

To get rid of this effect, it is necessary to have a plate which shall not be acted upon by the rays of greater refrangibility. Ordinary plates are, within the limits of exposure given in the camera, sensitive to the blue and violet rays only, but orthochromatic plates are made which are acted upon by the other end of the spectrum, although the maximum of sensitiveness is still in the blue-violet region. By using a screen of a deep orange tint, it is possible to cut off nearly the whole of the rays further than the green: such a screen in connection with orthochromatic plates furnishes a partial solution of the difficulty. It is, indeed, not entirely removed, because air absorbs, and therefore diffuses, not only blue and violet rays, but also those of lesser refrangibility; the effect of aerial perspective still exists, but instead of being exaggerated by photography, it is reduced.

The use of orthochromatic plates is not without its drawbacks. The shadows, in a landscape, receive their light from the sky, and it is this light, reflected into the camera, which forms the image. But the light of the sky is mostly blue and violet and does not act on the plate behind the orange screen; the result is that the shadows are much more intense than on ordinary plates.

The proportion between direct sunlight and skylight varies with the altitude of the sun and with the absorption of the atmosphere; the less light absorbed, the greater is the contrast. Shadows look more intense when the sun is high than when it is low, but it is in the mountains, at high elevations, that the contrast is greatest. In general, the air is very pure and the coefficient of absorption small; only rays of very short wave lengths are absorbed and diffused, and the sky assumes a strange deep blue tint. The thickness of the overlying atmosphere being so much less than at sea-level, the absorption is still further reduced and the shadows of the landscape become very intense. The effect is exaggerated by the orthochromatic plates with deep yellow screen.

It is now easy to understand why good photographs of Alpine scenery are so scarce; the wide contrasts present, ranging from snow in sunlight to dark pines in shade, and the intensity of the shadows combine to make them the most difficult subjects to photograph. Satisfactory results cannot be expected unless the very best plates are used.

Still another difficulty encountered is due to what is known as "halation." When photographing an object or landscape where strong contrasts are presented, the outlines of the brighter part of the image are likely to be indistinct or slightly blurred. This is caused by a certain amount of light penetrating through the film to the back of the plate, where it is reflected and then acts on the film from behind. There are two ways in which this is overcome. One method is by coating the back of the plate with a black or red substance of the same refractive index as glass, which will absorb all light which reaches it. This covering may be washed off either before or after development. The other is by using a double emulsion which forms a film of sufficient thickness to absorb all light falling on it and to prevent any from penetrating to the surface of the glass. It is customary to use a rather slow emulsion first and to put the faster one on top. This method should increase the latitude of the plate.

Until 1915, the plates used on Canadian topographical surveys were Cramer "isochromatic" or Seed "L Ortho." These plates had great latitude of exposure, were sensitive to yellow and green rays, and when used with a deep orange screen which reduced the effect of the more actinic part of the spectrum, i.e. the ultra violet to blue rays, gave good results. They could be handled safely in a deep ruby light sufficiently strong to permit the photographer to see clearly what he was doing. Since that time Wratten and Wainwright "panchromatic" plates have been used, along with a yellow screen made by the same company and known as a "G" filter. These plates are susceptible to all rays of light and have given excellent results, but, owing to their extreme sensitiveness, they must be handled in the dark, not only in the field but also in the developing-room. On account of this, there is no opportunity for controlling the development, and correct and uniform exposure is of the utmost importance.

Concerning exposure no definite rule can be given. Before commencing work it is customary to expose a number of plates giving different exposures under conditions as nearly as possible similar to field conditions. These plates

receive normal development and are carefully examined to ascertain which has given the best result. It will be found that two or three plates give almost equally good results, and from these the unit of exposure must be decided. This must not be the shortest possible unit—as that might lead to underexposure, a fault which must always be avoided—but should be about the average time of exposure of the good plates. If in doubt, it is always better to overexpose slightly than to underexpose. A small developing outfit is carried in the field, and one or two plates are developed occasionally to make certain that they are all right.

The following rules are given by Messrs. Hurter and Driffield. They adopt five different degrees of brightness; very bright, bright, mean, dull and very dull. “Very bright” is defined as the condition when the light comes from a clear unclouded sky, and “mean” is when there is just sufficient light to cast a faint shadow. “Very dull” is the dulllest light in which it would be reasonable to attempt to take a photograph. “Bright” is between very bright and mean, and “dull” is between mean and very dull.

Accordingly, if the unit of exposure for very bright light is two seconds, the relative exposures are as follows:

Very bright.....	2	Mean.....	4
Bright.....	3	Dull.....	8
Very dull.....	16		

Although the foregoing definitions and rules are somewhat vague and leave much to the judgment of the surveyor, they serve as a guide, and, after a little experience, will be found to give good results.

There are a number of other points that must be constantly remembered. Views looking under the sun will, in bright light, require two to three times the normal exposure. Light is much stronger in the middle of the day than in the early morning or late afternoon, and stronger also in May or June than later in the season. In Canada, after about the first of October, as the sun becomes lower, the shadows in deep mountain valleys become more intense, and it is impossible to obtain good views except near noon and under very favourable conditions. At high altitudes the light is more actinic than at sea-level, and also varies according to the latitude of the place.

The use of exposure meters will probably be one of the first methods of determining exposures that will occur to the beginner. There are many types of these on the market, but, although they may serve as useful guides in ordinary photographic work, it is doubtful if they would be of any value for views embracing such wide stretches of country as do those required in survey work. The surveyor must learn to use his own judgment and to form an estimate of the time required by the conditions of light and the appearance of the landscape.

In surveying, the subject is not of so much importance as in ordinary photography. The views cover large areas and are usually of a somewhat uniform character, so that it is generally possible to base the exposures upon the same unit throughout the season, though in case of views covering exceptionally dark valleys or large snowfields it is advisable to lengthen or shorten the exposure.

The following rules may be of assistance to beginners:—

Be sure that the tripod is rigid, especially if there is a strong wind blowing.

Always use the sunshade to cut out unnecessary light.

Never permit the sun to shine on the lens.

Avoid taking photographs directly under the sun, if possible, particularly if the sun is low. This may be avoided to some extent by taking the views to the right of the sun on first reaching the station and the views on the left just before leaving.

Use a small stop, not larger than  $f/32$ , and give a time exposure. It is safer to use the same stop throughout the season, as mistakes may be made if it is frequently changed.

After removing the slide, immediately before taking off the cap, see that the levels are in their proper positions. Remove the cap gently so as not to disturb the instrument.

If the sun is shining brightly and the landscape appears dull on account of haze or smoke, little or nothing can be gained by giving more than normal exposure.

If spare plates are available do not hesitate to duplicate any view which may seem doubtful.

Usually the best light for views is about ten or eleven o'clock, and an effort should be made to reach the station in time to take advantage of this. Frequently after noon the atmosphere is not so clear, although the light is more favourable for views to the east or southeast.

The subject of development is fully dealt with in many textbooks on photography, and many different formulæ and methods are advocated. Consequently it will not be discussed here although it is perhaps next to exposure, the most important operation. Much can be done by the expert photographer to control the development of the plate and to compensate for errors of exposure, provided they are not too large and provided the plate can be handled in a ruby light. Unless there is good reason for doing otherwise, the formulæ recommended by the manufacturer of the plates should be used. These formulæ have been carefully tested by elaborate experiments and are specially suited to the plates for which they are recommended.

The care of plates in the field, both before and after exposure, must be one of the first considerations under all circumstances. Plates are usually shipped in cases containing twenty dozen or more, and, if possible, are carried in these cases throughout the season. They are kept in the tent, though no doubt it would be better, if possible, to keep them where they would be less exposed to variations of temperature. In any event it is absolutely necessary that they be kept dry. When moving, whether by pack train or otherwise, the plates must be handled with the greatest care.

For changing plates, a dark-tent is used. This is a small tent made of one or more thicknesses of black sateen and one of red. It is either suspended from the top of the camp-tent or placed over three or four short stakes driven into the ground, and must hang low enough that the bottom can be tucked in to exclude all light. Though not more than twelve plate-holders are necessary, it is customary to carry two dozen, numbered from 1 to 24, for each camera. This enables the operator to change one dozen plates at a time and eliminates all trouble with part boxes and the increased liability of mistakes and resultant double exposure. In changing, the exposed plates are taken out of the holders and placed in the top of the box in pairs, face to face. The inner box is then opened, and, as the new plates are put in the holders each one is marked on one corner, by means of a soft pencil, with the number of the holder and the number of the dozen. The exposed plates are then repacked exactly as they were when packed by the maker, different methods being used for different brands of plates. This may seem an unnecessary precaution, but it has much to do with the success of the work, as the plates must often remain in the field one to three months, and must then be transported long distances before they can be developed. Of course the changing must be done in a very faint light, or, in the case of panchromatic plates, in absolute darkness, and is likely to cause the beginner considerable worry, but, if everything is ready and in proper order before entering the dark-tent and strict attention is given to the work, he will soon find it as easy as if in a dark-room. Moreover, he should remember that while too much light may cause fogged plates there is no danger from the other extreme, and, consequently, darkness is preferable even though he may find it a little awkward at first.

## 5. Enlarging

For plotting purposes, bromide enlargements, approximately 10 by 14 inches, are made from the negatives. To obtain satisfactory results, the enlarging must be accurately and uniformly done, and consequently this work is done at the head office in Ottawa with a camera constructed specially for the purpose. This camera is of very simple construction and of fixed focus, so that all enlargements may be of the same size. On account of its greater convenience and freedom from variation, artificial light is used.

Fig. 13 illustrates the principles on which it is constructed. A light-chamber *A* is provided with some source of artificial illumination such as a series of nitrogen lamps or a mercury tube. This light passes through a ground

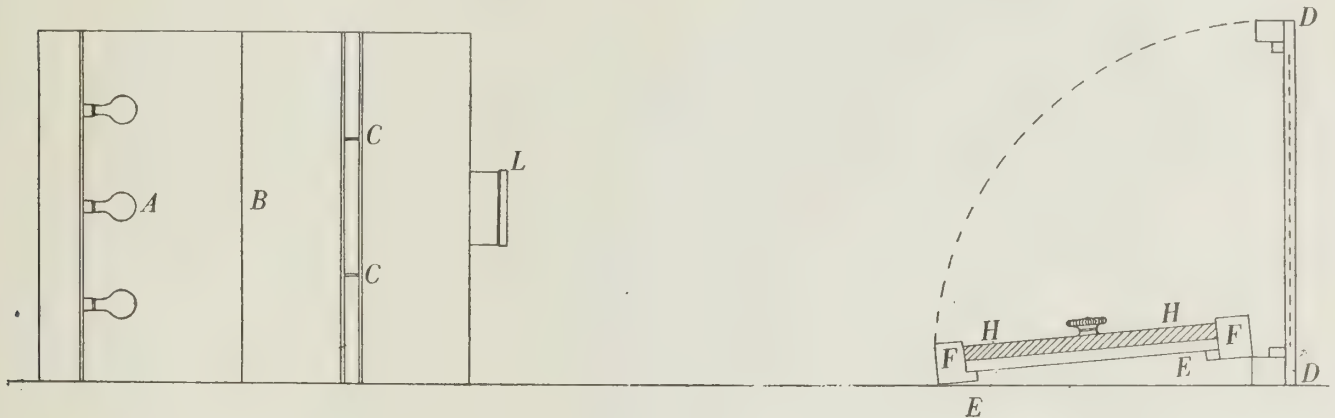


FIG. 13

glass, shown at *B*, and illuminates the negative, which is inserted in a plate-holder fitting tightly into the slot *CC*. The lens *L* is of long focus to avoid excessive distortion due to play of the negative-carrier or failure of the paper to lie in an absolutely flat plane. To hold the paper in position, a rectangular piece of plate glass *EE* a little larger than the paper, is placed in the holder *FF*. The paper is placed on top of this glass and is held firmly by the cover *HH*, which fits inside the holder and is fastened by means of springs similar to those used in printing-frames. The complete holder, which is hinged, is then raised and fastened inside the frame *DD*, which is rigidly attached to the camera base. It is essential that *CC* and *EE*, or the negative and the paper, should lie in parallel planes perpendicular to the optical axis of the lens.

In order to ascertain the change in the dimensions of the paper, eight small crosses are ruled on the plate glass in pairs, one pair on each side and another pair at each end. Those along the sides are 300 mm. apart and those along the ends are 200 mm. These are so arranged that they come just outside the image on the paper, and print white on the dark margin as shown in fig. 25. After the paper has been developed and dried, the shrinkage in either direction may be easily determined by measuring the distance between these marks and comparing it with the theoretical distance.

In so far as possible, prints required for one survey should be made from one set of paper as, by so doing, more uniform results can be obtained, because paper of different consignments, even though of the same grade photographically, may vary considerably in contraction. A grade of paper which will lie flat and not curl up when in use should be selected.

## 6. Field Work

Photographic methods are not applicable to every class of country. It is necessary that there should be bare summits suitable for stations, and that there should be sufficient relief to permit of the ready identification of the same points on views from different stations. Consequently the camera cannot be used in districts where all the hills are heavily timbered. Considerable work has been done in foot-hill districts where occasional bare points can be found and where

views in one or more directions can be obtained by partially clearing off other summits occupied. Owing to the difficulty, often impossibility, of getting stations where most needed and the absence of pronounced topography, the results are not entirely satisfactory. Still, a very fair map may be made showing all the main features and much of the detail, and, when criticising, it should be remembered that it is a difficult and expensive matter to accurately map country of this nature by any other method. It is, however, in the higher mountain ranges that the camera can be used to the greatest advantage. Here there is no difficulty in obtaining stations, and the mountains, with their bold, rugged outlines, afford much better photographic subjects than the rolling foot-hills. In addition to this, mountain views usually cover a greater area, and the identification of points may be accomplished much more rapidly and accurately than when dealing with less broken country.

There are many difficulties encountered in the field, among the first of which are those involved in climbing. On the lower slopes there is dense underbrush and windfall to struggle through, and, higher up, snow slopes and glaciers to cross, rock cliffs to climb and difficult arêtes to traverse. On the summit, the surveyor must work with an instrument set up on a pile of loose rock on the most exposed part of the peak, frequently suffering severely from cold and wind while doing so. These, however, are minor difficulties and not nearly as serious as those due to variations of light and sudden changes of weather. The surveyor cannot wait indefinitely for a suitable light but must use his own judgment regarding exposure. This is a difficult matter when cloud shadows are heavy, particularly in a country where there is but little contrast. Even on a fine day some views may require three to four times as much exposure as others. Often it is necessary to work rapidly in order to get through before an approaching storm breaks, or before clouds roll over the peaks and render further work impossible. Other causes of much trouble, particularly during the latter part of the season, are smoke from forest fires, dense haze and early snowstorms. In these circumstances the surveyor must decide under what conditions he can work profitably, and this depends very largely on the nature of the district. In alpine country or where valleys are narrow, serviceable views may be obtained under very unfavourable circumstances, but in rolling country or where great distances are involved, objects soon lose their distinctness. Good photographs can be obtained only under favourable circumstances, but much of a surveyor's success depends on his ability to get serviceable photographs under varying adverse conditions.

The surveyor must not be discouraged if considerable time is lost because of the unfavourable weather conditions above outlined. Under average conditions in the mountains the probable loss of time will range from one-quarter to one-third of the total time spent in the field, and in exceptionally unfavourable seasons or in a very wet climate, lost time may run as high as 75 per cent. Unfortunately he cannot exercise any control over atmospheric conditions, and all the surveyor can do is to endeavour to arrange his work so that he can take advantage of all opportunities offered.

When in the field, it is important to select those points which give the best views of the surrounding country. This does not mean that the highest peaks are always the best. In photographs taken from very high peaks, the surrounding country often appears dwarfed, and the detail does not show up as well as in those taken from a more moderate elevation. It must also be remembered that the higher the peak the longer the ascent will require, and the greater the likelihood of encountering sudden storms or floating clouds. Frequently, very useful views may be quite easily obtained from points of comparatively low altitude.

It is customary to take enough views from each peak to cover the complete circuit of the horizon. This means very little more work for the surveyor in the field, and the extra views are often of great assistance in the office. It seldom

happens that all the views can be taken from a single point, and usually one or more camera stations are required on different parts of the peak; indeed, sometimes all views must be taken from points at a distance from the transit station in order to avoid having the valleys cut out by projecting ridges. As a rule these camera stations may be located by reading angles on them from the main station and measuring the distances to them with a light tape, or, if the transit is equipped with stadia wires, stadia methods may be conveniently employed where chainage is difficult or impossible. Angles must be read on at least one well-defined point in each view, preferably on two or even more. Sketches of these points, if they are not stations or well-known peaks, should be drawn in the field book, so that there may be no difficulty in identifying them in the office. The angle of elevation or depression to each point should be recorded, as it will serve to check the position of the horizon line if it should be found later that the camera had not been properly levelled. Unless a camera station is very close to the main station, angles to the points selected in the views from it should be read from that station, particularly if the points are close, unless they have been fixed by triangulation or other methods.

Before leaving the station, a signal of some kind must be constructed in order to have a definite point to sight on from other points. If above timberline, this signal usually consists of a stone cairn from 4 to 6 feet in height, built on the highest point of the peak. In wooded country this is unsuitable and some kind of target or flag of white or black cloth is necessary. The nature of its construction will depend much on the distances of the stations from which it is desired to see it, and the degree of permanency required.

In selecting stations, the nature of the country must be considered. In rough country presenting broken ridges, snowfields and snowspots, large angles of intersection, varying from  $90^\circ$  to  $30^\circ$ , may be used without difficulty, particularly if the views from different stations are taken under similar conditions. In foot-hill districts, where these strongly marked features are missing, it is often impossible to identify points at these angles, and intersections of  $30^\circ$  to  $15^\circ$  must be used. This means that greater care must be exercised in choosing those stations that are to be used together, and that there must be a greater tendency to select them in pairs or groups than there would be in the more broken country. Greater care, also, must be used in identification and plotting if the same standard of accuracy is to be maintained.

## 7. Triangulation and Control

The accuracy of a photographic map depends first of all on the precision of the triangulation system controlling the survey. This may vary from a precise triangulation to a reconnaissance survey where the triangulation and the photography are carried on at the same time. The following remarks regarding the subject are quoted from *Photographic Surveying*:—

The triangulation may be executed at the same time as the topographical survey, but it is preferable to have some of the principal points located in advance by a primary triangulation.

The subject is fully treated in the standard works on surveying; very little requires to be added here. There exists, however, some misconception as to the order to be followed in the operations; a few words of explanation may prove useful.

A survey must be considered as consisting of two distinct operations; one has for its object the representation of the shape or form of the ground, the other the determination of its absolute dimensions. A perfect plan or triangulation can be made without the measure of any base or length; the plan will exhibit the various features of the ground in their exact proportions, but no absolute dimension can be measured on it until the scale of the plan has been determined. This is done by measuring on the ground one of the dimensions represented on the plan; so, the object of the measure of a base is to fix the scale of the survey and nothing more.

To execute a triangulation, the surveyor is recommended to commence by measuring a base and making it the side of a triangle, on which he is to build other triangles of increasing dimensions. There is a certain logical sequence in the order followed, but, in strict theory, the order is immaterial; the triangulation may be executed first and, when completed, connected with a base by triangles decreasing in size as they come near the base.

In practice, the case is different; there are several advantages in executing the triangulation first.

The selection of a base is governed by various considerations; the ground must be tolerably level and free of obstacles, and the direction, length, and position of the base must be such as to permit a good connection, by triangles of proper shape, with the main triangulation. The surveyor can make a better choice after he has been over the whole ground, than on his arrival when he has seen little of it. Having established the main triangles, he also knows best how to connect them with a base. In a mountainous country, the principal summits of the triangulation are fixed by nature and cannot be changed, while the position or direction of the base may generally be modified to some extent. Were the base measured first, it might be found not to connect properly with the main triangles.

The secondary triangulation is the work of the topographer, and the construction of signals on the secondary points should be his first act upon arriving on the ground.

Should the time at his disposal allow, he will not commence the survey proper until all signals have been established, otherwise he may have to measure angles between points not very well defined. When he does so, the closing error of a triangle is assumed to be due to the want of definition of the points.

Let  $A$ ,  $B$  and  $C$  represent the angles of a triangle whose summits have been occupied in the order given. At  $A$ , the surveyor observes the angle between  $B$  and  $C$ , where there are no signals. He puts up a signal at  $A$  and moves to  $B$ . In measuring the angle between  $A$  and  $C$ , he has a signal at  $A$  and none at  $C$ . Placing a signal at  $B$ , he measures the third angle  $C$  between two signals.

Call  $\alpha$  the closing error of the triangle and  $\epsilon$  the probable error of a sight on a point without signal. The probable errors of the angles are:

$$\begin{array}{ll} \text{For } A, & \epsilon \sqrt{2} \\ \text{" } B, & \epsilon \\ \text{" } C, & 0 \end{array}$$

The corrections to the angles must be proportional to the probable error of each; they are:

$$\begin{array}{ll} \text{For } A, & \frac{\alpha}{1 + \sqrt{\frac{1}{2}}} \\ \text{" } B, & \frac{\alpha}{1 + \sqrt{2}} \\ \text{" } C, & 0 \end{array}$$

The closing error must not exceed a certain limit fixed by the degree of precision of the survey; when the limit is exceeded, the stations must be reoccupied, commencing at the most doubtful one.

The stations of the primary triangulation are the last ones to be occupied when they have been established by a previous survey.

To have a correct idea of the work he is doing, the surveyor must make in the field a rough plot of his triangulation, on which he marks all the stations occupied. It shows him the weak points of the survey and enables him to plan his operations with more assurance.

The object of the secondary triangulation is to fix the camera stations; its summits are selected for that purpose only. All the topographical details of the plan are drawn from the camera stations.

Where both operations are carried on simultaneously, the surveyor must occupy his first station before any signals are erected on the neighboring peaks. From it he must sight on points which appear likely to be future stations, and on the more important peaks, drawing sketches, if necessary, to assist in remembering them. From his second station he sights on the first and again on the proposed future stations and prominent peaks, using as far as possible the points previously selected and, if advisable, expanding to other peaks. Following this method throughout the season, a reasonably solid system of triangulation is built up notwithstanding the lack of definition of many of the points used, and it will be found at the end of the season that usually the location of a station depends on the mean of a number of sights on it or from it, generally both.

A station may be located in the following ways:—

1. Two sights on it from fixed points having a good angle of intersection.
2. One sight on it from a fixed point, and two sights from it on fixed points subtending a large angle of intersection. One of these sights may be on the point from which the station itself is sighted, or both sights may be on other points.
3. Three sights from it on fixed points subtending good angles of intersection.

The first case requires no explanation.

In the second, the line of sight to the station is laid down. On a piece of tracing paper, a point is taken to represent the station, and the two lines of sight are plotted. The tracing paper is then placed on the plan and moved around until the point lies on the fixed line of sight and the lines from the station pass through those sighted upon.

In the third case, the lines of sight are plotted on a piece of tracing paper as before; then the paper is placed on the plan and moved until the lines of sight pass through the proper stations.

Although the above conditions are sufficient to locate a station theoretically, particularly if the system is controlled by a precise triangulation, they represent the minimum information necessary. Other conditions—more sights on the station, more sights from it, or both—must be obtained whenever possible especially in the case of a reconnaissance graphically plotted, where the result depends more on the mean of a number of sights than on the accuracy of any particular ones. Where a number of known points have been sighted on from one station, as is usually the case, all sights are plotted on tracing paper as in the previous case, the paper is placed on the plan and then shifted to obtain the best possible position. If sights from other stations already plotted have been taken on the one required, these should be plotted and considered when deciding on the position.

Camera stations must not be located by means of the photographs, as the accuracy is not sufficient.

The triangulation for a survey of this class may depend upon a measured base, or a transit and chain traverse of a railroad or valley passing through the district. Transit and stadia traverses of some of the main streams have been found satisfactory, provided a check on the accuracy of the work can be obtained. Where this method is used, the stations on peaks overlooking the valley are established first and are afterwards located by angles read at the traverse stations. If it is possible to do so, some signals should be placed in open parts of the valley before beginning work, so that they may be sighted on from the camera stations and then tied in by the traverse at a later date.

Along a railway or where points of known elevation can be obtained, the altitudes of the stations are computed from these directly, if possible, or through the traverse. If the traverse runs for a long distance through rough country, the elevations are carried forward trigonometrically by vertical angles, and the altitude of each transit station determined. From these altitudes, those of the adjacent camera stations are found. The elevations of the more remote points are in turn computed from these, the mean of a number of sights being used for each one. Wherever distances of a mile or more are involved, the proper correction must be made for curvature and refraction.

It is customary, on plans, to refer all elevations to mean sea-level, but although this is the most convenient and satisfactory system, others may be used. For example, when an isolated survey is required in a remote district, it may happen that no reliable bench-marks have been established, and in such a case an elevation for some point must be assumed and those for the survey based on that. To avoid confusion, this assumed elevation must be sufficiently large that all resultant elevations will be positive. A map thus constructed will give an accurate representation of the terrene, and at a later date the altitudes may be reduced to sea-level if desired.

## 8. Scale of Plans

The scale of the plan will depend on the purpose for which it is to be used. Almost any scale or contour interval may be adopted. The early Canadian surveys were plotted on a scale of 1/20,000, with a contour interval of 100 feet, and reduced to a scale of 1/40,000 for publication. Some later surveys were plotted on a scale of 1/80,000 with a 250-foot contour, and for reconnaissance

maps still smaller scales have been used. The writer considers it rather dubious whether very small scales can be used to advantage and thinks it preferable to plot the plan on a larger scale and have it reduced in publication. If the scale is too small, it becomes almost impossible for the topographer or draftsman to draw in the detail, whereas, if the plan is drawn on a larger scale, even though no additional points are plotted, more detail can be sketched in without extra work, and the final plan, when reduced, will give a much better representation of the country than will be obtained if the small scale is used throughout. For general purposes the writer has found a scale of  $1/40,000$  and a contour interval of 100 feet very convenient for large plans. In all cases, the scale used for plotting should be larger than the scale on which the plan is to be published. If the map is enlarged, the draftsman's inaccuracies and the lack of minor details, which are probably undesirable on the original plan, become much more noticeable and tend to destroy the original effect, but, if the plan is reduced, these things are less evident and the general appearance of the plan is improved.

For detailed plans of small areas, much larger scales must be used, and the decision will depend largely upon the purposes for which the map is intended. In a district where suitable camera stations can be obtained, very accurate maps can be made by photography on comparatively large scales.

In deciding on the horizontal scale, it is obvious that the contour interval and the nature of the country must be considered. For example, if using a small scale, such as  $1/40,000$  or  $1/50,000$ , it would not be possible to use a 20- or 50-foot interval in mountain districts, as the contours would be so close together that the topographer would be unable to draw them in many places. On the other hand, if much detail and a large scale plan is required, contours 20 or 50 feet apart may not be sufficient to define the topography, particularly in rolling country. In any case the contours must be sufficiently close to give a good representation of the terrene on the scale required. It is preferable that the interval should be 100 feet or some multiple such as 200 or 500 feet, or, in large scale maps, 10, 20 or 50 feet, as these can be more readily converted into the larger intervals if at a later date the publication of the plan on a small scale is required.

Throughout the field work the number of stations to be occupied will be largely determined by the proposed scale of the plan. If only a sketch map on a small scale with a large contour interval is required, the topographer must occupy stations that will give clearly the principal features, such as the main ridges and divides between water-courses with sufficient elevations to control the contours in the valleys, depending on sketching to fill in what detail is required. As the scale becomes larger and the contour interval smaller, more stations must be occupied and more attention paid to detail.

## 9. Perspective

As previously stated, it is not intended to deal with this subject from a theoretical standpoint. Although there are a number of constructions which may be used to advantage in the office and which are of interest to the student, the greater part of the work must be done by two or three methods which soon become a matter of routine. Of these, the most important is that of plotting points by intersections. Still, as the application of photography to mapping is based on the principles of descriptive geometry and perspective, in discussing the subject certain terms are frequently used, and it is necessary that these should be clearly understood along with certain fundamental properties of lines in perspective.

Descriptive geometry deals with the orthogonal representation of objects on two intersecting planes known as the "planes of projection." These planes are usually assumed to be at right angles, one horizontal and the other vertical, their line of intersection being known as the "ground line."

Let  $XDY$  (fig. 14) represent a horizontal plane called the "ground plane," and let  $XCY$  be a plane perpendicular to it and intersecting it in the line  $XY$ . Then,  $XCY$  is called the "vertical plane" and the line  $XY$  the "ground line." A line  $AB$  in space will be defined by its projections  $ab$  on the ground plane and  $a'b'$  on the vertical plane. Now, if the plane  $XCY$  be revolved around the line  $XY$  until it coincides with the plane  $XDY$ ,  $a'b'$  will fall into the position  $a''b''$ . Then,  $ab$  is called the "horizontal projection" of the line  $AB$ , and  $a''b''$  the "vertical projection." In orthogonal drawing, this is represented as shown

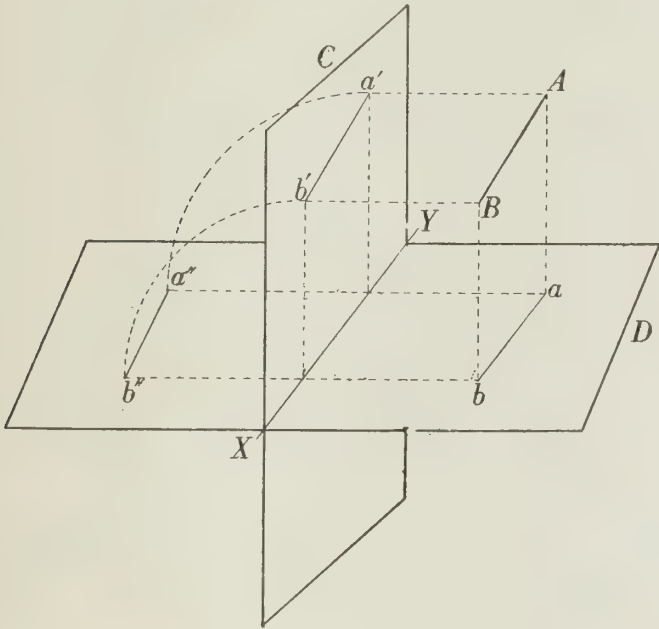


FIG. 14

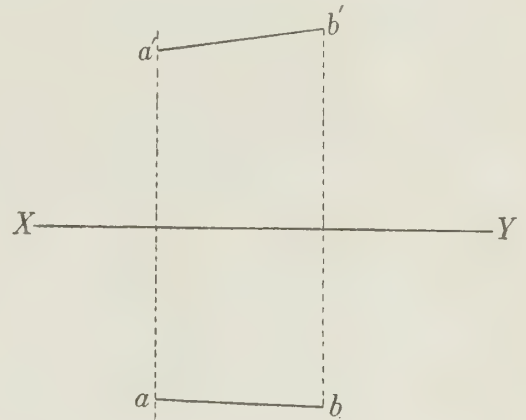


FIG. 15

in fig. 15, the line  $AB$  being assumed in front of the vertical plane and above the ground plane. If differently situated, the positions of the projections with reference to the ground line will be altered accordingly.

In dealing with perspective the following introductory remarks and definitions are quoted from Dr. Deville:—

"Perspective" is that branch of geometry which treats of the representation by figures drawn on a surface of objects placed beyond it. Generally this surface is a vertical plane; it is called the "picture plane." The figures drawn on it, according to the rules of perspective, produce on the eye, as far as form is concerned, the same impression as the objects themselves seen in their actual places.

Suppose a transparent plane surface, such as glass, placed between the eye and the objects to be represented. If the outlines of the objects seen through the glass could be traced on it, the image thus formed would be an exact perspective.

Consider the visual ray from the eye to a point in space; this ray pierces the picture plane in a second point, which is called the "perspective" of the first one.

The visual rays from the eye to all the points of a straight line form a plane whose intersection with the picture plane is the perspective of the line. Consequently, the perspective of a straight line is another straight line.

When the line is a curve, the visual rays to its various points form a conic surface whose vertex is at the eye and whose intersection with the picture plane is the perspective of the curve. A surface of the same nature is formed by the visual rays tangent to the visible outline of an object; the perspective of the object is the intersection of this surface by the picture plane.

The "ground plan" is the horizontal projection of the objects to be represented; thus, for the perspective of a landscape, the ground plan is the topographical plan of the ground; for a building, it is the horizontal or ground plan of the building. ( $ABCD$ , fig. 16).

The "ground plane" is the plane on which the ground plan is placed ( $KXsY$ , fig. 16). For a landscape, it may be, for instance, the horizontal plane passing through the datum point of the topographical plan, and for a building, the basement or first-floor plane. Any horizontal plane may, however, be used as ground plane, provided its altitude be taken into account; the ground plan does not change, whatever the altitude may be.

The "elevation" is the vertical projection of an object; the elevations of a building are those plans of the building which show the front, rear, or sides.

The "picture plane," as already explained, is the plane on which the perspective is drawn ( $FFXY$ , fig. 16). Generally, it is vertical and placed between the eye and the object to be represented, but none of these rules is absolute. Perspectives are sometimes drawn on planes which are not vertical and objects are represented which are between the picture plane and the

eye. Such a position of objects is the rule and not the exception in perspectives used for surveying, when they are taken as representations, not of the ground itself, but of a model of it reduced to the scale of the map. This convention will be found farther on. Objects are even represented which are behind the observer, the origin of light, for instance, in the construction of shadows, but this is merely a geometrical conception to which the usual definition of a perspective does not apply.

The "ground line" is the intersection of the ground and picture planes ( $XY$ , fig. 16).

The "station" is the point supposed to be occupied by the eye of the observer. ( $s$ , fig. 16).

The "foot of the station" is the point where the vertical of the station pierces the ground plane. (S, fig. 16).

The “principal point” is the foot of the perpendicular drawn from the station to the picture plane; it is shown in  $P$ , fig. 16.

The "distance line" is the line between the station and the principal point ( $SP$ , fig. 16). Its length is the distance from the station or from the foot of the station to the picture plane.

The "horizon plane" is the horizontal plane passing through the station. It contains the distance line and cuts the picture plane on a horizontal line passing through the principal point and called the "horizon line" ( $HH$ , fig. 16). The distance between the horizon line or the principal point and the ground line is equal to the altitude of the station.

The "principal plane" is the vertical plane perpendicular to the picture plane and passing through the station (*SNQ*, fig. 16). It contains the foot of the station, the principal point and the distance line.

The "principal line" is the intersection of the principal and picture planes ( $QN$ , fig. 16). It is perpendicular to the ground and horizon lines and intersects the latter at the principal point.

A “front plane” is a plane parallel to the picture plane.

A “front line” is any line contained in a front plane, therefore any line parallel to the picture plane.

It has already been shown that the perspective of a straight line is the intersection with the picture plane of the plane containing the station and the given line.

Draw a plane through the straight line  $AB$  in the ground plane and the station  $S$  (fig. 17). The intersection  $\alpha\beta$  of this plane with the picture plane is the perspective of  $AB$ . Thus we have the following relation between a straight line in the ground plane and its perspective; they

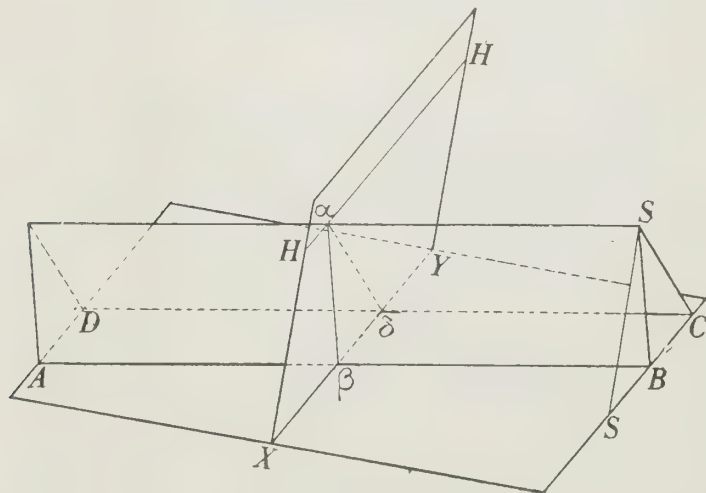


FIG. 17

the ground plane and the station  $S$  (fig. 17). The plane is the perspective of  $AB$ . Thus we are in the ground plane and its perspective; they are the traces on the ground and picture planes of the plane containing the station, and the line itself. Let us now suppose that we have a second line  $CD$  parallel to  $AB$  and also in the ground plane. As before, pass a plane through the station and the line  $CD$ . This plane will intersect the picture plane in the line  $\alpha\delta$ , and the plane through  $AB$  in the line  $\alpha S$  which passes through the station parallel to the ground plane and therefore meets the horizon line at  $\alpha$ . Hence, the perspectives of all parallel lines in the ground plane meet in the point where the parallel line drawn through the station intersects the picture plane. It may readily be seen that this remains true for all lines parallel to the ground plane and to each other. If the lines are not parallel to the ground plane, their vanishing point

may still be found by drawing a parallel line through the station to intersect the picture plane, but this intersection will no longer lie on the horizon line.

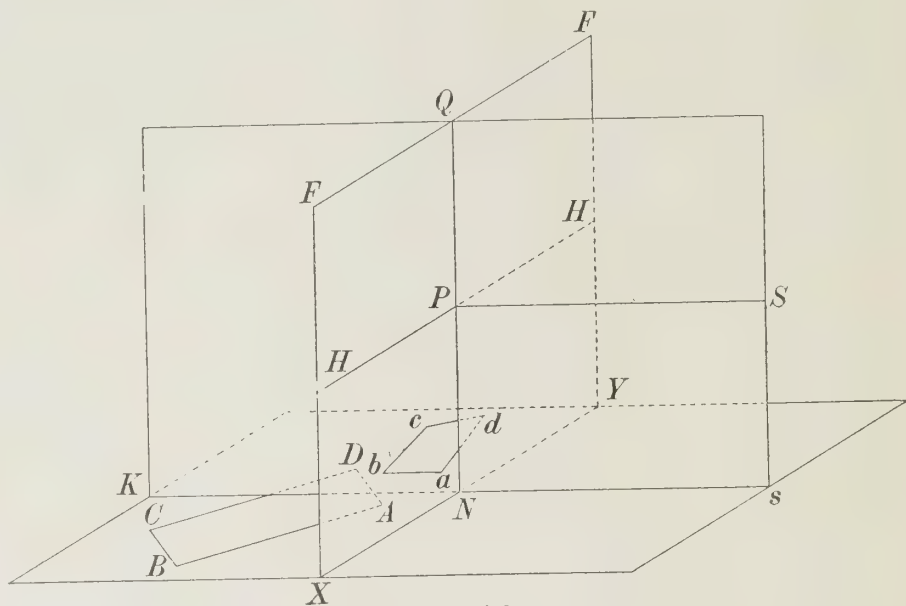


FIG. 16

A horizontal line has its vanishing point on the horizon line because the parallel drawn through the station, being horizontal, is all contained in the horizon plane and has its vertical trace on the horizon line.

Perpendiculars to the picture plane, being parallel to the distance line, have for vanishing point the vertical trace of the distance line which is the principal point of the perspective.

The vanishing points of horizontal lines making an angle of  $45^\circ$  with the distance line are called "distance points,"  $DD$ , (fig. 18); their distance from the principal point is equal to the distance line because a horizontal line inclined at  $45^\circ$  to  $SP$  forms an isosceles triangle  $SPD$  in which  $SP = PD$ .

Lines in the principal plane have their vanishing point on the principal line. Two of these lines form angles of  $45^\circ$  with the distance line, one above and the other below the horizon. Their vanishing points are known as "upper and lower distance points"; they are also at the same distance from the principal point as the station.

A straight line parallel to the picture plane is contained in a front plane and is represented in perspective by a line parallel to itself; therefore, parallel lines which are also parallel to the picture plane have parallel lines for perspectives and have no vanishing point. The parallel to the given lines passing through the station, being parallel to the picture plane, has no trace on it.

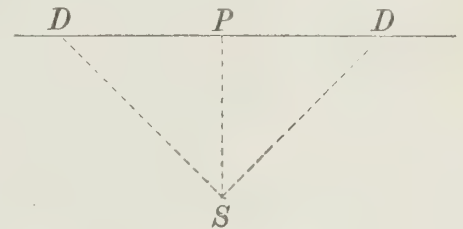


FIG. 18

Vertical lines are parallel to the picture plane and appear in perspective as parallels to the principal line.

Horizontal lines parallel to the picture plane are in perspective parallel to the horizon line.

## 10. Perspective as Applied to Photographs

In perspectives used for surveying, the lens takes the place of the eye and forms on the negative an exact image of the landscape.

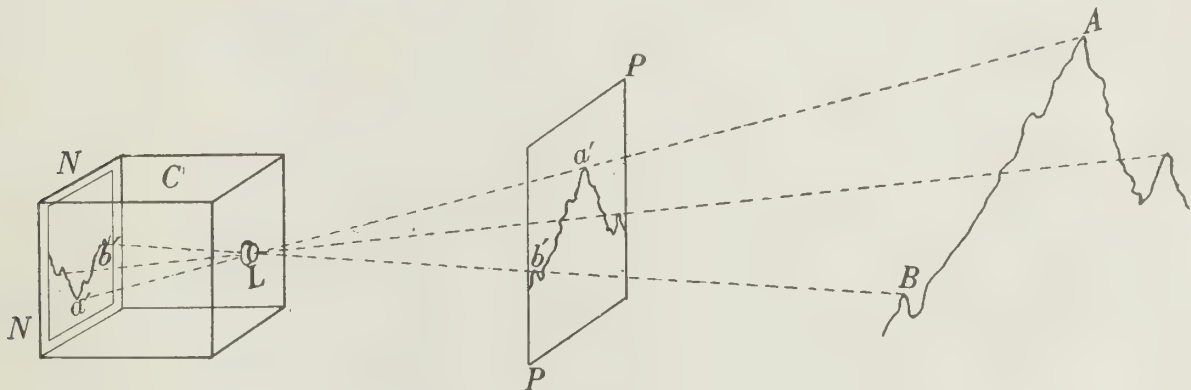


FIG. 19

This is illustrated in fig. 19, where  $C$  represents the camera,  $L$  the lens, and  $NN$  the negative, which is behind the lens and on which the image appears inverted. Points such as  $A$  and  $B$  appear as  $a'$  and  $b'$ , but when a print or an enlargement is made the image is again reversed, and the result is as though the picture were drawn on a plane  $PP$  interposed at the proper distance between the lens and the object, this distance being dependent on the size of the picture. If both the negative and the picture are in parallel planes perpendicular to the axis of the lens, as they should be, the perpendicular distance from the centre of the lens to the negative is the focal length of the lens, and that from the lens to the picture plane is the focal length of the enlargement. This statement is made on the assumption, usually fulfilled in work of this class, that the objects to be photographed are sufficiently distant that no change of focus is required in the camera, although photographs may be made to any size required.

In mapping, it is generally the case that on the plan the projection of the terrene will lie inside the focal length of the enlargement or between the lens and the plane of the picture. Then the picture may be regarded as an enlarged perspective of a model of the ground on a small scale.

In connection with this subject the following points must be remembered:—

When dealing with instruments, provision was made for placing the negative in a vertical plane during exposure, for fixing the horizon and principal lines in the photograph, and for finding the principal point. Emphasis was laid on the necessity of careful enlarging, so that all views taken with the same camera should be exactly the same size or, in other words, have the same focal length. Although the latter condition may not be absolutely necessary if the tests described below are rigidly applied, excessive variation will cause much annoyance and delay throughout the office work.

Before using the photographs, it is necessary to check them for distortion or uneven contraction of the paper.

With a pair of dividers, check the distances  $EP$ ,  $PF$ ,  $GP'$ ,  $P'J$ ,  $AB$ , and  $CD$  (fig. 20) each of which is equal to one-half the focal length, or, if the focal length is greater than the side of the camera, to some known fraction of it. If all these distances are equal or in proper proportion and the principal and horizon lines are at right angles, the view is ready for use. If it is found faulty, a new enlargement should be made.

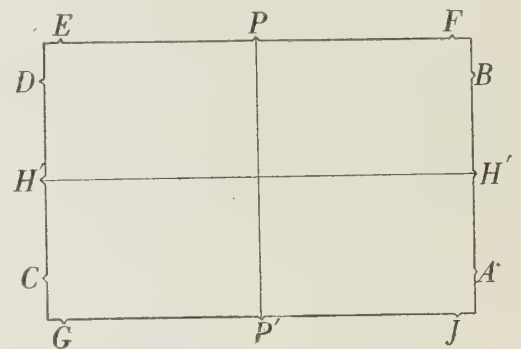


FIG 20

Referring again to fig. 19, it is apparent that if the photograph  $PP$  is placed in its proper position the direction of any point such as  $A$  may be obtained by drawing from  $L$  a straight line to  $a'$ , producing it if necessary. This line of sight will be represented on a plan by its projection, which will be the intersection of the ground plane, or plane of the plan, with the vertical plane passing through the lens and the point. This is the same principle by which angles between points of different altitudes are measured with the transit. By means of the levels, the lower graduated circle of the transit is placed in a level plane, and the telescope revolves in a plane at right angles to it, so that the angles measured are the horizontal angles between the vertical planes containing the points. It is because of this that angles of elevation or depression do not have to be considered when plotting lines of sight from a station, although they are necessary if it is required to fix the position of the point in space. This is what is actually required in a contour map. The plan shows the projection of the point on a plane surface, while the contours show its elevation with respect to other points.

In fig. 19, it is quite evident that the line  $LA$  or its projection on the plan is not sufficient to locate the position of the point either in space or on the plan. It merely gives its direction with reference to  $L$ , or with respect to the station occupied, so we see that one perspective is not sufficient to locate a point. But if on a second view from a known station it is possible to locate the same point and to find the line from it to the point, the two lines must meet in that point. Hence, the position of the point in space will be given by the intersection of the lines of sight from the two stations, and the position of the point on the plan will be at the intersection of their projections. In other words, its projection will be the place where the perpendicular drawn from the point in space meets the ground plane.

In fig. 21, let  $MN$  and  $M'N'$  be views from two stations  $A$  and  $B$  whose projections on the ground plane, represented by the paper, are  $a$  and  $b$ . To avoid making the diagram unnecessarily complicated,  $B$  is not shown but lies vertically above  $b$ . Then, if the view  $MN$  is placed in its proper position as seen from the stations, the vertical plane in which it lies will intersect the ground plane in  $TT$  and will also be perpendicular to the principal line  $AP$ . Then

$TT$  is the trace of the view, and  $ap$  is the trace of the principal plane or of the principal line  $AP$ . Similarly,  $T'T'$  is the trace of the picture  $M'N'$ , and  $bp'$  the trace of its principal line.

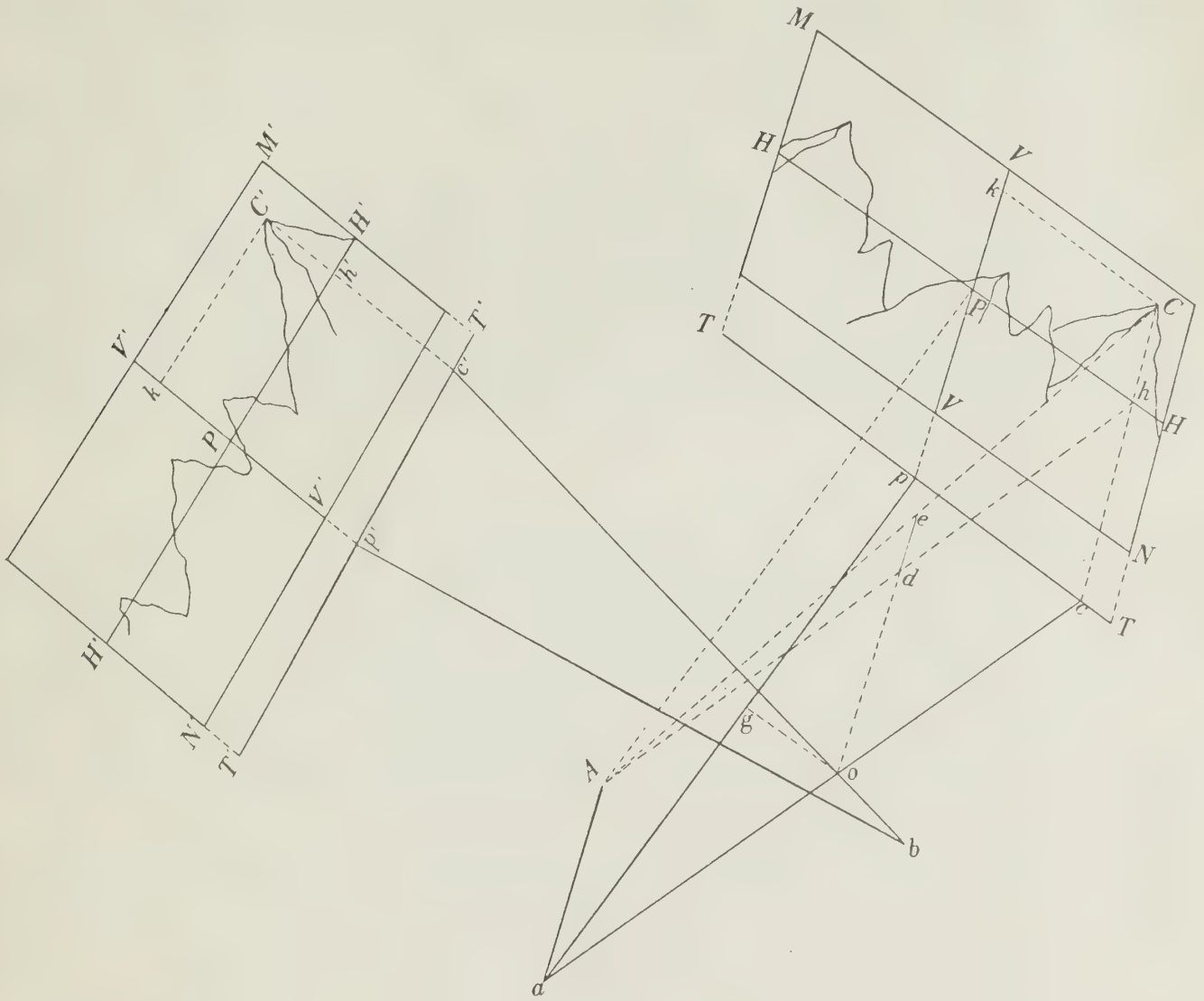


FIG. 21

Now consider any point  $C$  on the view  $MN$ . The line of sight from  $A$ , the actual position of the station in space, is  $AC$ , and the horizontal projection of this line on the ground plane is the line  $ac$ , obtained by joining  $a$  to the point  $c$  where a perpendicular drawn from  $C$  pierces the ground plane. The position of  $c$  may be obtained by making  $cp$  equal to  $Ck$  since  $kp$  and  $Cc$  are parallel both lying in the plane  $MN$  and both perpendicular to the ground plane. It is evident that the projection of  $C$  must lie on the line  $ac$  or  $ac$  produced.

If on the view  $M'N'$  a point  $C'$ , corresponding to the point  $C$ , can be identified, the line  $bc'$  can be laid down as in the previous case, and the position of the point must be at  $o$ , the intersection of the two lines.

The horizon line  $HH$  of the photograph  $MN$  lies in the same horizontal plane as the station  $A$  from which it is taken, and the elevation of  $C$  above it is represented by the line  $Ch$ . Therefore, if the value of  $Ch$  is known, it is only necessary to add this value to the known elevation of the station (or subtract it if the point lies below the horizon line) in order to find the altitude of  $C$ .

Now, since  $Aa$  and  $Cc$  are both perpendicular to the ground plane  $AC$ ,  $Ah$  and  $ac$  are in the same vertical plane, and if a vertical line is drawn at  $o$ , it must also lie in the same plane and will intersect  $AC$  and  $Ah$  in  $e$  and  $d$ .

But, by the conditions of similar triangles and parallelograms,

$$de: Ch = Ad: Ah = ao: ac$$

$$\text{or } de = \frac{ao}{ac} \cdot Ch$$

where  $ac$  and  $Ch$  are known quantities depending on the focal length of the view and  $oa$  is the horizontal distance of the point  $C$  from the station, depending on the scale of the plan.

This may be expressed in another form, for, if a perpendicular  $og$  is drawn from  $o$  to the principal line,

$$ao : ac = ag : ap$$

$$\text{or } de = \frac{ag}{ap} \cdot Ch = \frac{ag}{F} \cdot Ch$$

Usually this determination is made graphically, but if computed it will be found convenient to express all quantities in feet according to the scale of the map. The resultant value of  $de$  will also be in feet.

These equations give a method of finding the horizon line under certain conditions. Suppose  $C$  is the perspective of a station, plotted at  $o$ , whose altitude is known. If the elevation of  $A$  is subtracted from that of  $C$ , the result will be the value of  $de$ .

$$\text{Now, } Ch = de \cdot \frac{F}{ag}$$

which will give the value of  $Ch$  expressed in feet. If, then,  $Ch$  is made equal to the value found, according to scale in use, the point  $h$  must be on the horizon line. If another station appears on the other side of the view, a corresponding point may be found and the horizon line drawn by joining the two points.

In practice, these problems are solved graphically, and it is seldom that a mathematical calculation is made. Still, the principles have been explained at some length in an attempt to give the reader a clear understanding of the significance of the solution, which in practice is performed mechanically without thought as to its meaning.

It may be useful at this point to call attention to the characteristics of certain lines which may be required frequently when working on photographs.

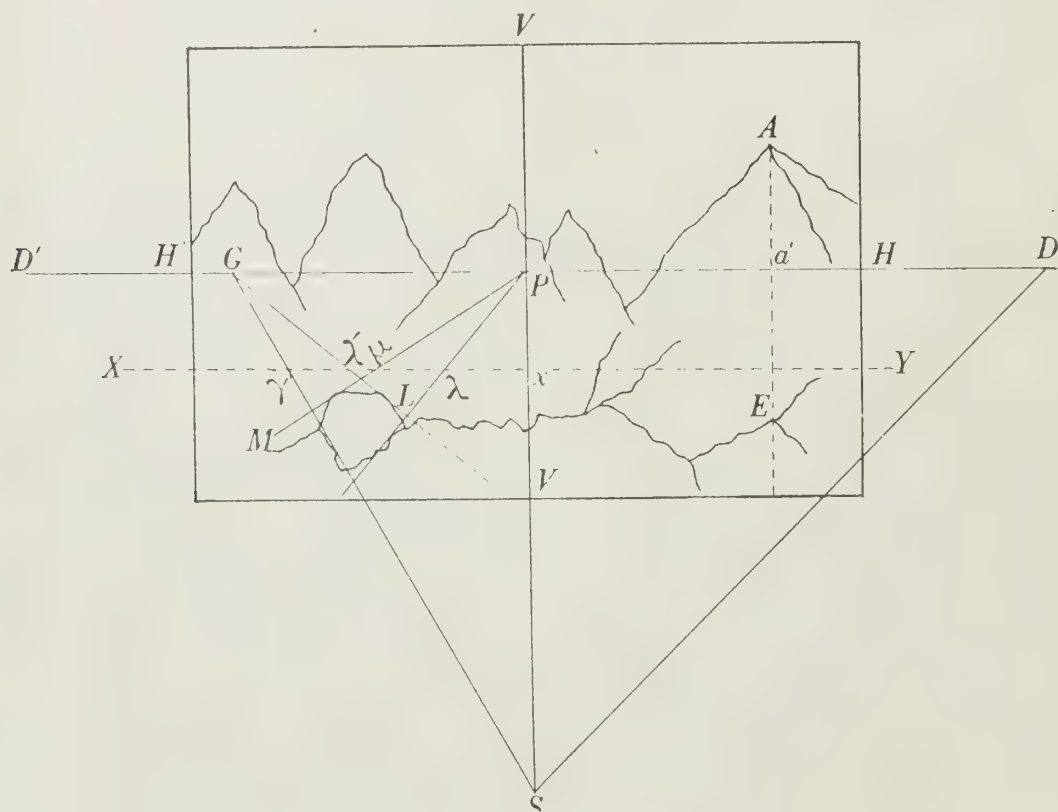


FIG. 22

Let  $HH'$  and  $VV$  (fig. 22) represent the horizon and principal lines of a photograph whose principal point is at  $P$ , and, in fig. 23, let  $s$  represent the station,  $sp$  the principal line and  $dd'$  the trace as laid down on the plan. Let  $A$



## 11. Identification of Points

As the survey is plotted chiefly by intersections, in accordance with the principles already outlined, the first operation after plotting the control is to identify on different views the points to be laid down. For this purpose, views from two different stations showing the same area are taken, and common points on both views are identified. These points should be along ridges, streams, changes of slope, etc., and should be selected so as to define the topography as accurately as possible with a minimum number of points. The number necessary will depend much on the nature of the terrene, as a rough, badly broken district will require many more points than one where the natural features are comparatively uniform. Care should be exercised to select points that can be accurately identified on both views, especially if the intersections are acute. It is also advisable to check occasionally the plot of certain well-defined points by a third or even a fourth line of sight where possible. This is of special importance where a ridge is to be plotted from two sides, as, by using different sets of views, the summit may be more accurately located and the points on either side placed in better relative position than if only one intersection is used. At first, the identification of points may cause some trouble, but with a little practice this will soon be overcome and the topographer will find that he can select points rapidly and without difficulty on photographs taken under varying conditions.

In practice it does not often happen that any given area can be mapped from two stations, as from any one station much of the topography is hidden by projecting shoulders or intervening ridges. Views from other stations, looking into side valleys and basins, must be utilized to fill in detail wherever possible, the intersections being checked by common points to make certain that all points are being plotted in their proper relative positions.

On the views, the points are marked by a dot and a number in coloured ink. These numbers usually run from 1 to 100, as too many in any one group are rather difficult to handle. Other colours are used for other groups, so that on the plan, and as far as possible on the views, no two sets entered in the same colour will be adjacent. This avoids confusion on the plan and makes it much easier to look up any required point, either on the views or on the lists which are kept as a record of the elevations.

## 12. Plotting of Points and Determination of Elevations

After the points have been identified, a strip of paper *CC* (fig. 24), one-half to three-quarters of an inch wide and a little longer than the view, is taken. A line *vv*, perpendicular to the edges of the slip, is ruled near the centre. Keeping *vv* on the principal line of the view, the distances of the points 1, 2, 3, etc., from the principal line *vv* are marked on the slip as shown. The slip is then reversed, and, on the opposite side, the distances of the points above and below the horizon line *HH* are marked in a similar manner. On the side of the slip showing the horizontal distances it is customary to write the name of the station and the number of the view, and on the opposite side the number of the view and the elevation of the station, using the same coloured ink as for the points. The distances may be marked in pencil or ink.

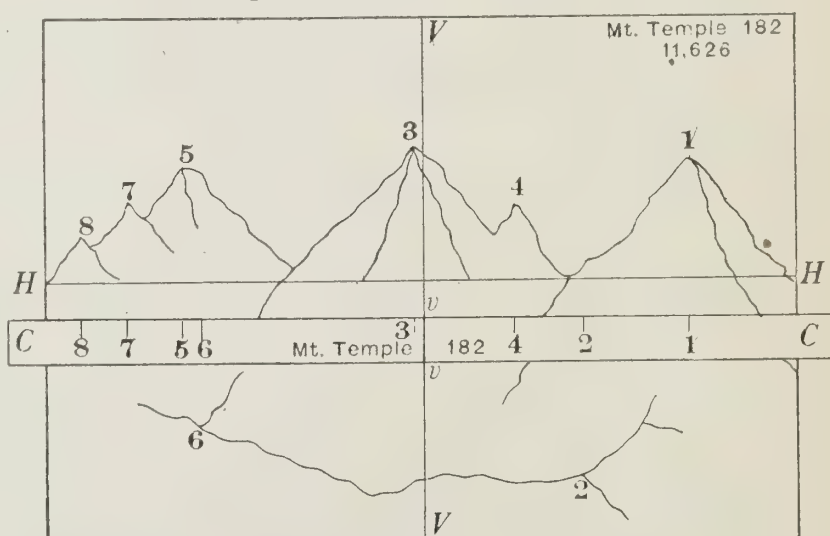


FIG. 24

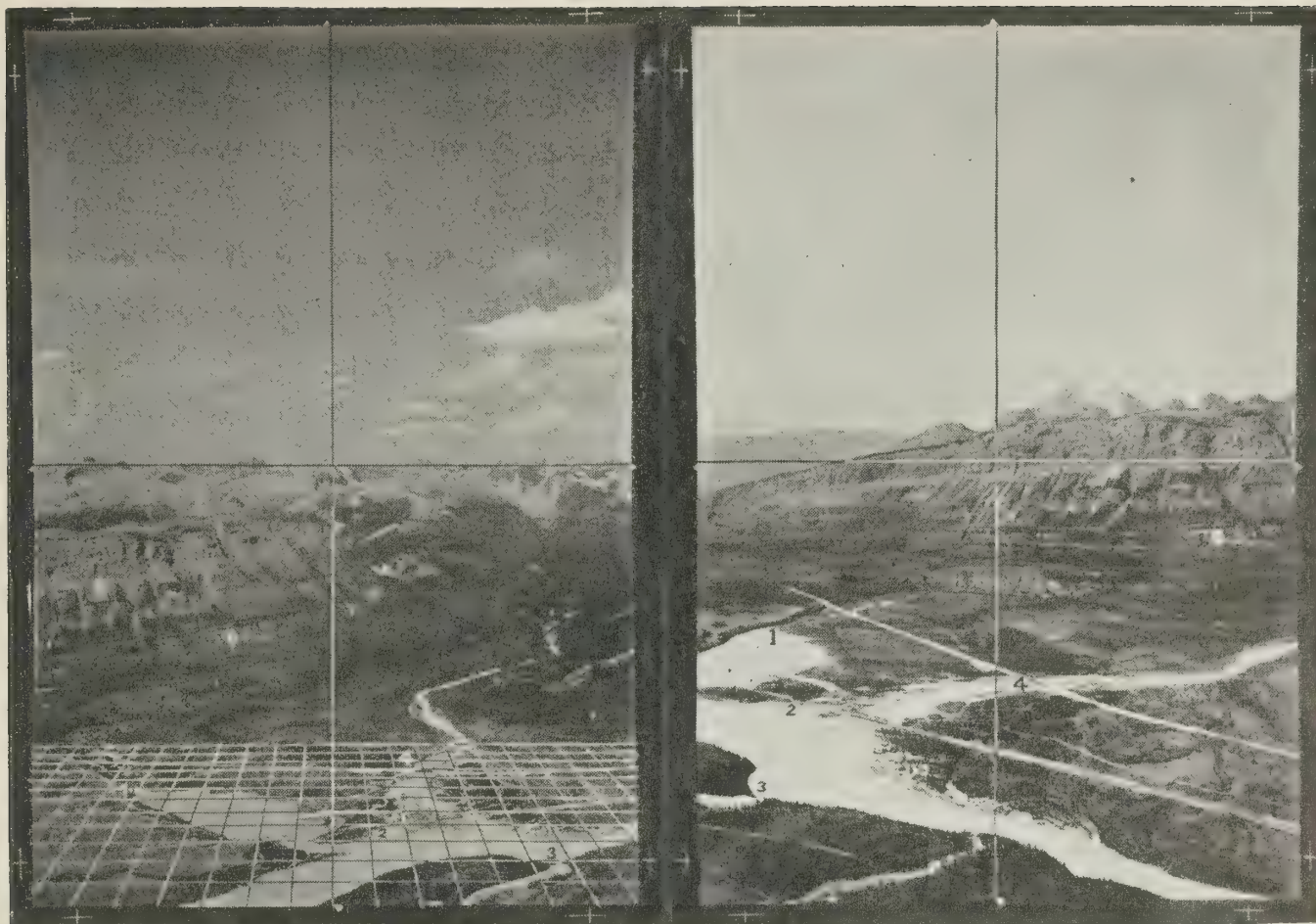


FIG. 25

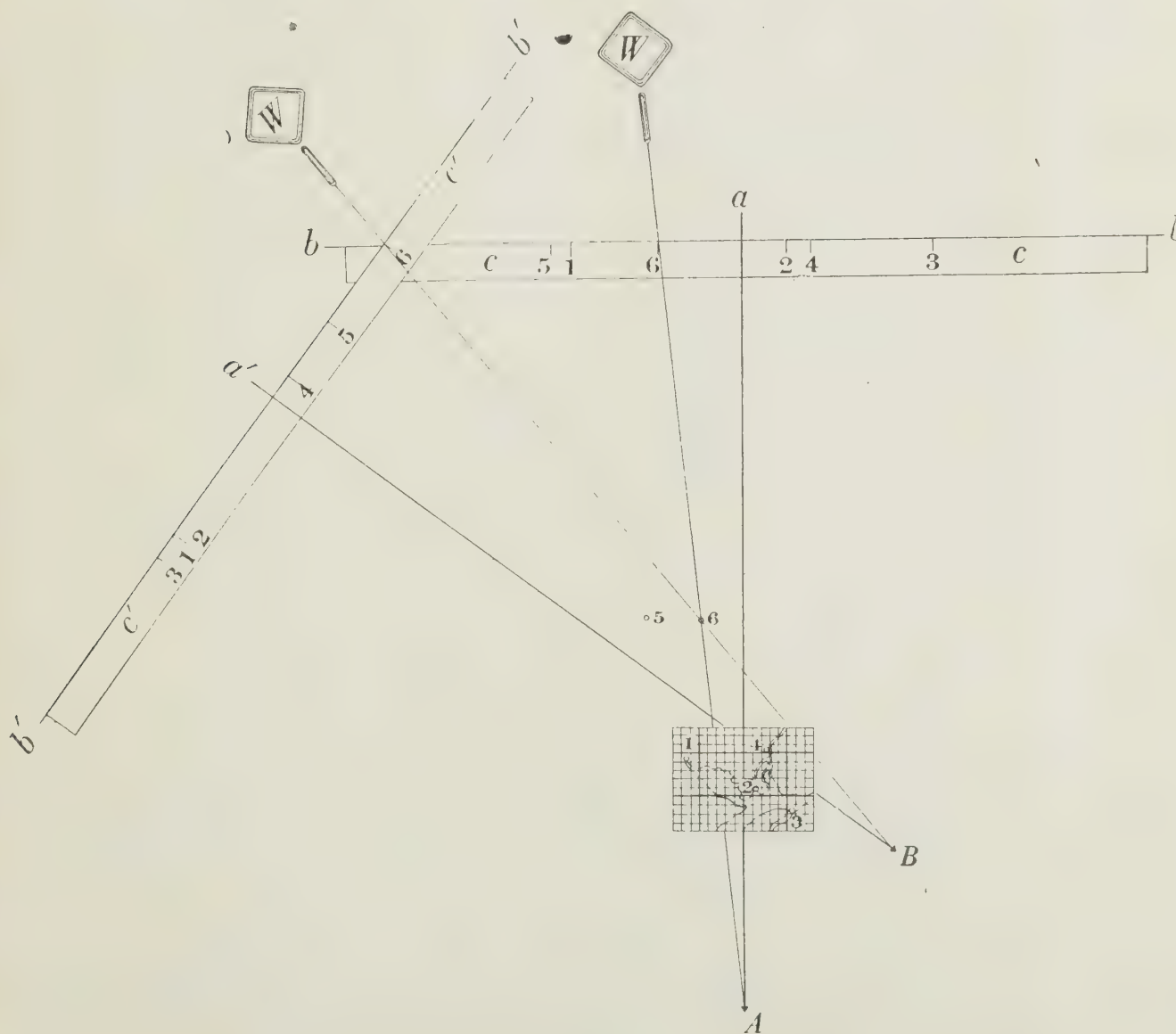


FIG. 26

Fig. 25 represents views from two different stations shown as  $A$  and  $B$ , fig. 26. On these views, points 1 to 6 have been identified, and the horizon and principal lines have been ruled on the views in their proper positions as shown by the test views. The traces of the principal lines and the picture planes are then laid down as shown in fig. 26. The lines from the stations  $A$  and  $B$  to  $a$  and  $a'$  represent the principal lines of the views, and  $bb$  and  $b'b'$  represent the respective traces. The slips,  $cc$  and  $c'c'$ , showing the distances of the points from the principal lines, are placed on their proper traces as shown. Then the line of sight from the station to any point is found by drawing a straight line from the station to the projection of the point shown on the slip, and the position of the point is given by the intersection of two or more of these lines of sight. Instead of drawing lines on the plan, needles are inserted at the stations and the intersections are determined by means of fine threads or hairs. Loops are tied at the ends to slip over the needles, and the other ends are attached to small weights. To secure sufficient tension without breaking the hairs, they are tied to small rubber bands and these in turn are fastened to the weights. In fig. 26, these weights are represented by  $W$ ,  $W$ , and the hairs are shown intersecting at the point 6. The points are pricked on the plan with a fine needle or pricker and are marked with the number in coloured ink as on the view.

The geometric construction for laying down the traces is as follows:—

Let  $a$  and  $b$ , fig. 27, represent two known points, either triangulation stations or points to which angles have been read by the transit. Produce the principal line  $VV$  to  $F$  making  $PF$  equal to the focal length. Find the projections  $a'$  and

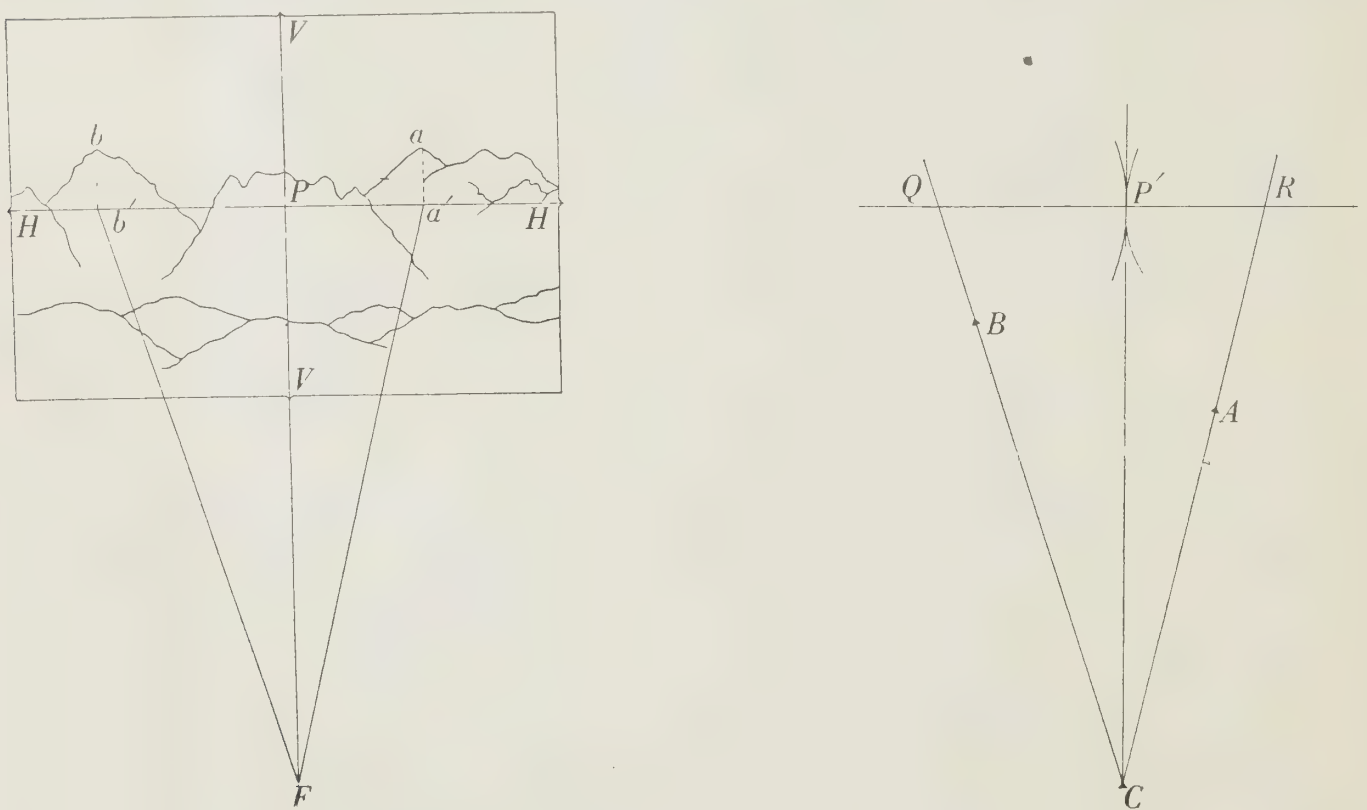


FIG. 27

$b'$  of  $a$  and  $b$  on the horizon line and measure the distances  $Fa'$  and  $Fb'$ . In the second part of the diagram,  $C$  represents on the plan the station from which the view is taken and  $A$  and  $B$  the two points. Draw lines from  $C$  through  $A$  and  $B$  and make  $CR$  and  $CQ$  equal to  $Fa'$  and  $Fb'$  respectively. With  $R$  and  $Q$  as centres and radii  $Pa'$  and  $Pb'$  respectively, describe arcs of circles as shown. Draw  $CP'$  and join  $QR$ . Then  $P'$  is the projection of the principal point and  $QR$  is the trace of the picture plane. If there is any inaccuracy in the location of the stations or in the other work, the two arcs will not be tangent to each other and the mean position will have to be used.



brass, fastened rigidly together.  $P$  and  $Q$  are sliding bars moving on the arm  $M$ .  $R$  is a swinging arm revolving around the centre  $O$ ;  $P$  and  $R$  are made of transparent celluloid and on  $R$  a fine line  $rr$  is ruled radiating from the centre  $O$ . The arm  $Q$  carries a scale corresponding to the scale of the map. The instrument must be made accurately so that when the line  $rr$  is over the line  $S$ , the reading of the scale will be constant when moved along the arm  $M$ .

When using the instrument, the centre  $O$  is placed over the station, and the arm  $P$  is placed so that the one edge coincides with the trace of the view, the line  $S$  falling on the principal line. The instrument is then held in place by heavy paper-weights. The distances of the points above or below the horizon line as shown on the views is taken off on a slip of paper. The slip is placed on the arm  $P$ , as shown in the diagram, and held in position by the clips  $pp$ . The scale is now set to read the elevation of the station when the line  $rr$  is above  $S$ . To obtain the elevation of the point  $\delta$ , the arm  $Q$  is moved to the point plotted, and the arm  $R$  moved so that  $rr$  passes through  $\delta$  as shown on the slip. The elevation of the point is now given by the reading of the scale where it is intersected by  $rr$ . To avoid mistakes, the elevation of each point is taken from two views and the mean of these two elevations is used.

If the points are far away from the station, it will be necessary to add an approximate correction for curvature. This may be done by marking on the arm  $R$  distances for which the corrections will be 5, 10, 15, . . . feet, and adding these corrections to the elevations read on the scale. Greater or smaller intervals may be used according to the accuracy desired.

If the instrument for computing elevations, which has just been described, is not available, the following method may be adopted using the angular scale shown in fig. 30.

After plotting the points, take a strip of paper slightly longer than the focal length of the view, and, keeping one end on the trace, mark on the slip the perpendicular distances  $p1$ ,  $p2$ , of the points from the trace. Also mark on the slip the focal length  $ps$  and then place the slip on the scale as shown so that  $s$  falls on  $S$ , the vertex of the scale. With a pair of dividers, measure the distance of the point 2

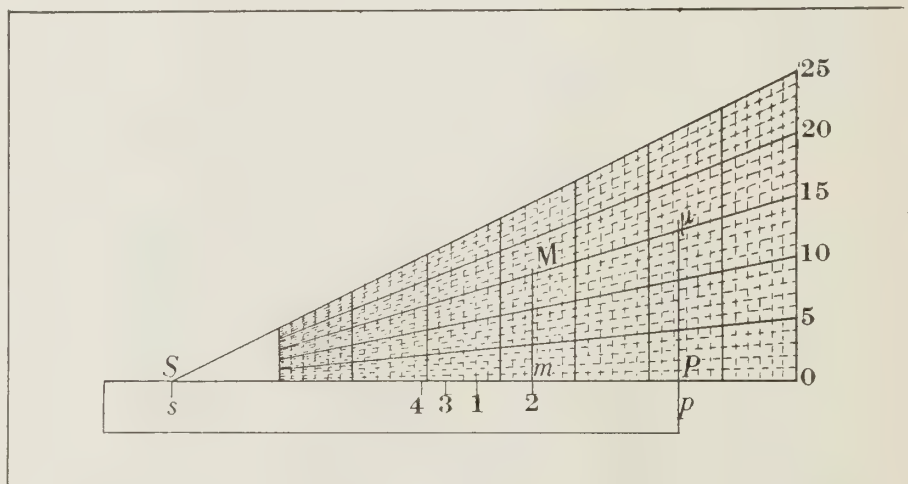


FIG. 30

above or below the horizon line of the view, and let the distance be  $P\mu$ . Note the reading of the scale at  $\mu$  which is 16 in the figure, and measure the same reading on the scale above the point 2. This is  $Mm$  which represents the difference of altitude between the point and the known elevation of the station and must be added or subtracted according as the point is above or below the horizon line of the view. The vertical lines on the scale merely serve as guides, so that all measurements may be made perpendicularly to  $PS$ .

The addition or subtraction may be performed mechanically in the following manner:—

A scale similar to that of the plan is pinned or otherwise fastened in a convenient place, perpendicular to a line  $AB$  (fig. 31) so that the division  $C$  corresponding to  $AB$  gives the height of the station. When the line  $Mm$  (fig. 30)

has been found as above, one leg of the dividers is placed at  $C$  (fig. 31) and the other falls in  $D$  so that  $CD$  is equal to  $Mm$ . The reading of the scale at  $D$  gives the elevation of the point.

The distances of the points from the horizon line of the view may be measured on a small slip of paper in the same way as their distances from the traces, and the slip placed so that its edge falls along  $P\mu$  (fig. 30). If one end of a thread is fastened to a needle at  $S$  and the other to a small weight as when plotting, the thread may be moved to pass through the different points marked on the vertical slip, and the difference of altitude read off on a scale held at the corresponding points on the horizontal slip.

As before, the elevation of each point is computed from two views and the mean of the results accepted, provided this difference is not beyond the limits of error. An excessive difference indicates an error in identification, in plotting or in determining the elevations. These must be checked, or, if the point is an important one, a third intersection should be used if possible.

After the elevations have been determined, they are marked with ink beside the points on the plan, all being entered in the same colour. To avoid confusion, this colour is used solely for this purpose and is not used for numbering points.

To avoid drawing unnecessary lines on the plan, the traces may be laid down and the points plotted on a good grade of tracing paper and afterwards transferred. This avoids the necessity of laying any traces down on the plan except those actually required. In this way the plan can be kept much cleaner, as it is used very little except for contouring.

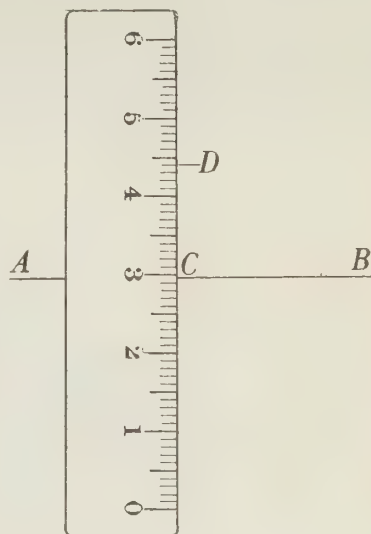


FIG. 31

### 13. The Perspectometer

Relatively level features such as swamps, lakes, or rivers with comparatively small fall are plotted by means of squares. The perspective of a series of squares is laid down on the photograph and the projection, on the proper scale, is drawn on the plan. Then, from the view, the required outlines are drawn on the projection, square by square, as carefully as possible. In practice these squares are not ruled on the views, but an instrument called the "perspectometer" is used instead. This consists of the perspective of a series of squares ruled on plate glass, having the distance line equal to the focal length. It is prepared by making a reduced photograph of a drawing on a large scale and then making a positive from the negative. The instrument is placed in its proper position on the view, and the features sketched on the projection as before. The perspective of a series of squares is shown on the first view of fig. 25 and the projection with the topography is shown in fig. 26.

The perspectometer may be constructed in the following manner:—

Draw a straight line  $DD'$  (fig. 32) and make  $DP$  and  $PD'$  equal to the focal length. Draw  $PA$  perpendicular to  $DD'$ , and through  $A$  draw  $BC$  parallel to  $DD'$ , making  $PA$ ,  $AB$  and  $AC$  each equal to the focal length. Divide  $AB$  and  $AC$  into any number of equal parts—for example, ten—as shown in the diagram, and join  $P1$ ,  $P2$ ,  $P3$ ..... All these lines are the perspectives of lines in the ground plane parallel to the principal line. Join  $BD$ ,  $AD$  and  $CD'$ . These are the perspectives of lines in the ground plane making angles of  $45^\circ$  with the principal plane and vanishing in the distance points  $D$  or  $D'$ , the line  $AD$  representing a line passing through the foot of the station. These lines must represent

diagonals of the required series of squares, and the positions of the sides parallel to the picture plane may be obtained by drawing lines  $aa', bb', cc', \dots$  parallel to  $DD'$  or  $BC$  through  $a', b', c', \dots$ , the intersections of  $AD$  with  $P1, P2, P3, \dots$ . Other squares may be obtained by joining  $Pa, Pb, Pc, \dots$  and continuing the construction as shown.

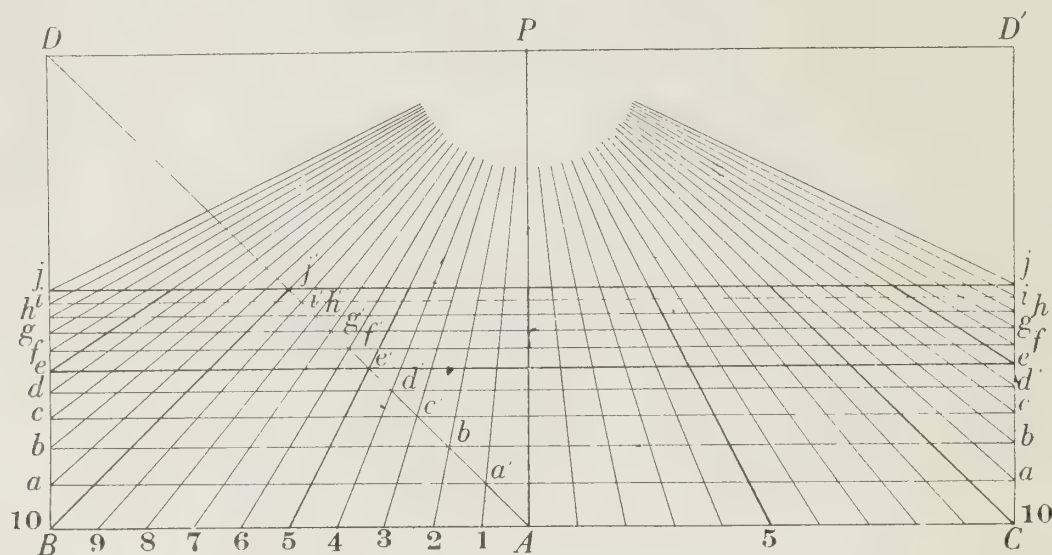


FIG. 32

The same result may be obtained by producing  $AB$  and dividing it into parts equal to  $A1$ , and joining the points of division to  $P$ . These lines will intersect  $BD$  in  $a, b, c, \dots$ , and  $aa, bb, cc, \dots$  may be drawn parallel to  $BC$ .

The division of  $AB$  into ten parts is arbitrary; any suitable proportion may be selected in order to obtain squares of the required size. These squares must be large enough to be easily plotted on the plan and small enough to enable the topographer to draw the required outlines accurately. If the difference of elevation between the station and the ground plane (which is, for the time, assumed to be the plane containing the feature to be plotted) is not great, and if the plan is on a small scale, it will be advisable to divide  $AB$  into less parts, as, for example five. The size of the squares to be laid down on the plan depends on the number of these divisions. When  $AB$  is divided into ten parts, as in the figure, the sides of the squares will be one-tenth of the difference of elevation between the station and the ground plane. For example, if it is required to lay down a lake 5,000 feet below the station, the sides of the squares on the plan will be 500 feet, but, if  $AB$  had been divided into five parts, the sides would have been one-fifth the difference, or 1,000 feet.

When in use, the perspectometer is placed on the view, so that  $DD'$  falls on the horizon line and  $PA$  on the principal line. On the plan, the sides of the squares perpendicular to the ground line are obtained by measuring the proper intervals from the principal line and drawing parallels to it. The positions of the other sides or front lines are determined by estimating the position of one or more lines with respect to a well-plotted point. This is done by noting the position of the point in a square of the perspectometer and laying down a line on the projection in the proper relative position. For example, if a point appeared to be midway between two front lines, the position of the line above would be found by measuring 250 feet (provided the squares were 500 feet as above) beyond the point and drawing a line perpendicular to the principal line. Other lines may then be drawn at equal distances.

A perspectometer can be used only for photographs having the same focal length or distance line, and any variation of the focal length will necessitate a new instrument. It is not necessary that the whole diagram be shown on the glass. All required is that the width  $DD'$  must exceed that of the photograph, and that the height  $PA$  must be sufficient to cover the distance between the horizon line and the bottom of the picture. Neither is it necessary to lay down

more squares on the projection than are actually needed to cover the features to be plotted. The number and the positions of these may be easily ascertained from the perspectometer.

Fig. 33 may help to explain why the sides of the squares are a fractional part of the difference of elevation. Let  $TRY$  represent the picture plane,  $XYF$  the ground plane,  $XY$  the ground line,  $HH$  the horizon line and  $P$  the principal point.  $S$  is the station and  $e$  the foot of the station, so that  $Se$  and  $Pe'$  are equal and perpendicular to the ground plane. Through  $SP$  draw the planes  $PSa$ ,  $PSb$ ,  $PSc$  and  $PSd$ , cutting the ground line in  $a'$ ,  $b'$ ,  $c'$  and  $d'$ , so that  $a'b'$ ,  $b'c'$ ,  $c'd'$  and  $d'e'$  are equal. These planes, having a common line of intersection  $PS$ , will cut the ground plane in lines  $aa'$ ,  $bb'$ ,  $cc'$  and  $dd'$  parallel to  $ee'$  and equidistant from each other. They also intersect the picture plane in  $a'P$ ,  $b'P$ ,  $c'P$  and  $d'P$ , and, as previously pointed out, these lines are the perspectives of  $aa'$ ,  $bb'$ ,  $cc'$  and  $dd'$ , which appear to vanish in  $P$  when produced beyond the picture plane. Now, if the plane  $PSa$  is drawn so as to make an angle of  $45^\circ$  with the ground plane,  $e'a'$  will be equal to  $e'P$  or  $eS$ , the height of the station above the ground plane, and therefore  $a'b'$ ,  $b'c'$ ,  $c'd'$  and  $d'e'$  will each be equal to one-fourth that difference.

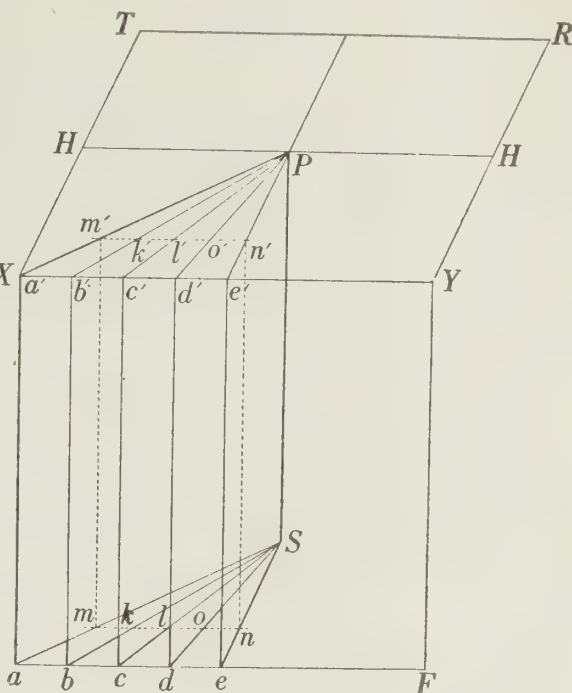


FIG. 33

It is evident that this condition is independent of the position of the ground plane, for, if another plane  $m n n' m'$  is selected, the difference of elevation becomes  $Sn$  or  $Pn'$  instead of  $Se$  or  $Pe'$ , but  $m' n'$  remains equal to  $Pn'$ , and  $m'k'$ ,  $k'l'$ ,  $l'o'$  and  $o'n'$  remain equal to one-fourth the difference of elevation.

In the construction given for the perspectometer (fig. 32) the ground line  $BC$  was assumed at a distance  $PA$ , equal to the focal length, below the horizon line. This was done in order to obtain a simple relation between the ground line, the principal point and the vanishing points.

#### 14. Vertical Intersections\*

In the method of horizontal intersections, the base line is projected on the horizontal plane; in this method it is projected on a vertical plane. The difference of altitude of the two stations must therefore be considerable.

The principal plane of one of the photographs is taken as the vertical plane of projection; the ground plane is the horizontal plane containing one of the stations. In fig. 34, the ground

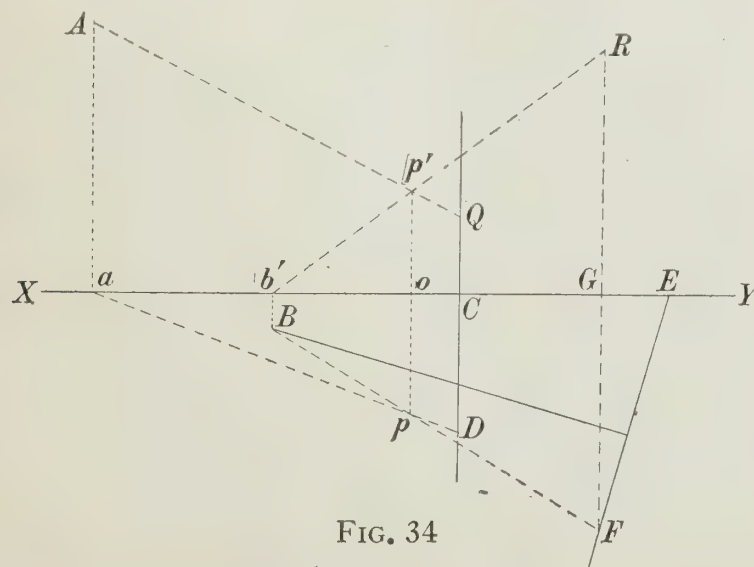


FIG. 34

line is the trace of the principal plane of the photograph taken from the station  $A$ ; the ground plane is the horizontal plane of the station  $B$ . On the ground plan,  $a$  and  $B$  are the two stations,  $CD$  and  $EF$  their picture traces. The station  $A$  on the vertical plane is on the perpendicular  $aA$  to  $XY$  equal to the height of  $A$  above  $B$ . A point such as  $p$ , plotted by the method of horizontal intersections, would not be accurately fixed because the angle of the directions  $aD$  and  $BF$  is too small.

Project the visual rays from  $A$  and  $B$  on the vertical plane; the visual ray from  $A$  is a line  $AQ$  passing through the projection  $Q$  of the point's image on the principal line. It is drawn by taking  $CQ$  equal to the height of the point on the photograph above the ground line, and joining  $AQ$ .

\*Dr. E. Deville, *Photographic Surveying*.

The vertical projection of the visual ray from  $B$  is a line  $b'R$  passing through the vertical projections of the station  $b'$  and of the point's image  $R$ , on the second photograph. To find  $R$ , let fall  $FG$  perpendicular to  $XY$  and produce to  $R$ ,  $GR$  being equal to the height, on the photograph, of the point's image above the horizon line.

The intersection of  $AQ$  and  $C'R$  is the vertical projection  $p'$  of the point. Letting fall the perpendicular  $p'o$  to  $XY$  and producing, determines the position  $p$  of the point on the ground plan.

The construction gives not only the point on the ground plan but also its height  $op'$ . This process is the best one for plotting a narrow valley between two high walls; it has, however, the disadvantage of requiring a complicated construction.

## 15. Photographic Board\*

So many construction lines are employed on the photographs that it is advisable to have a photograph board on which part of the lines are drawn beforehand, once for all.

It consists of an ordinary drawing-board covered with strong drawing-paper. Two lines at right angles,  $DD'$  and  $SS'$  (fig. 35), represent the horizon and principal lines;  $PD$ ,  $PD'$ ,  $PS$  and  $PS'$  are each equal to the focal length, so that  $D$ ,  $D'$ ,  $S$  and  $S'$  are the left, right, lower and upper distance points, respectively.

The photograph is pinned in the centre of the board, the principal line coinciding with  $SS'$  and the horizon line with  $DD'$ . Four scales, forming the sides of a square  $OTYZ$ , are drawn in the centre, the side of the square being a little larger than the length of a photograph.

They answer various purposes as, for instance, drawing parallels to the horizon or principal lines by laying a straight-edge on the corresponding divisions of the scales or marking the ground line by joining the divisions of the vertical scales representing the height of the station.

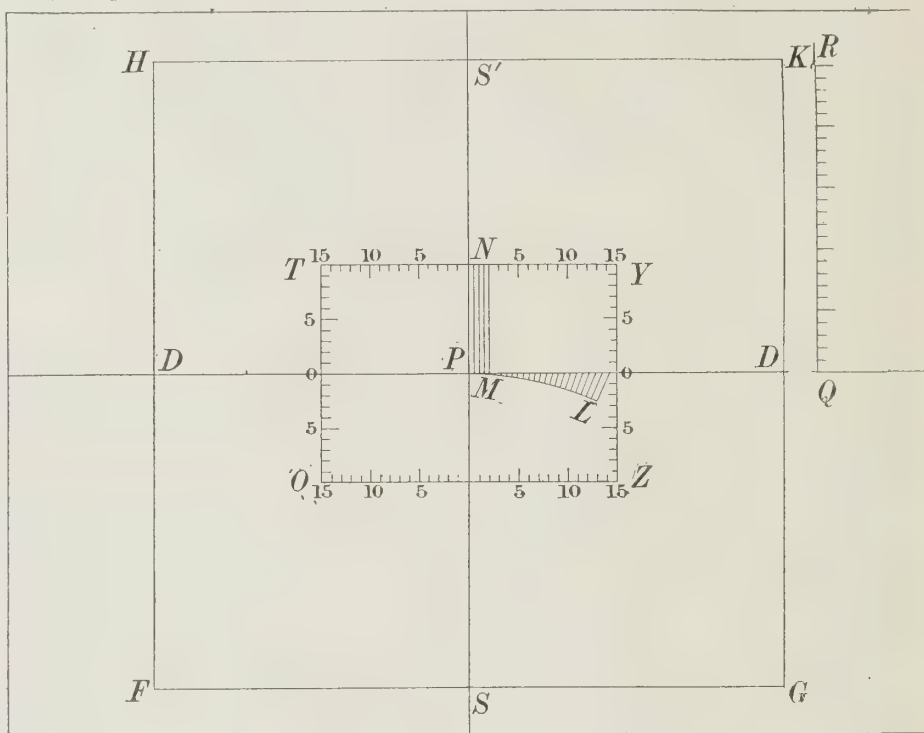


FIG. 35

At a suitable distance from the distance point  $D'$  a perpendicular  $QR$  is drawn on which are marked, by means of a table of tangents, the angles formed with  $DQ$  by lines drawn from  $D$ . This scale is employed for measuring the altitudes, or azimuthal angles of points of the photograph, as will be explained later on. From  $S$  as a centre with  $SP$  as radius, an arc of circle  $PL$  is described and divided into equal parts. Through the points of division, and between  $PL$  and  $PD'$ , lines are drawn converging to  $S$ . Parallels  $MN$  to the principal line are also drawn sufficiently close together. All these lines are used in connection with the scale of degrees and minutes  $QR$ .

A square  $FGKH$  is constructed on the four distance points.

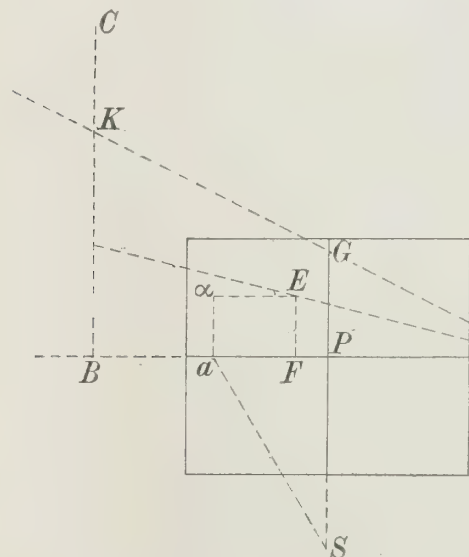


FIG. 36

The angle between the point of a photograph and the principal and horizon lines, that is, the altitude or azimuthal angle, is sometimes wanted. The azimuthal angle is obtained at once on the photograph board by joining the station  $S$  (fig. 36) to the projection  $a$  of the point on the horizon line. If required in degrees and minutes, the distance  $Pa$  is transferred to the principal line in  $PG$ ;  $D$  is joined to  $G$  and produced to the scale of degrees and minutes  $BC$ , where the graduation  $K$  indicates the value of the azimuthal angle.

Were many such angles to be measured, the horizontal scales  $TY$  and  $OZ$  (fig. 35) might be divided into degrees and minutes by means of a table of tangents, using as radius the focal length  $SM$ . A straight-edge being placed on a point of the photograph and directed to pass through identical divisions of  $TY$  and  $OZ$ , would at once give the azimuthal angle of the point.

The altitude is the angle  $S$  (fig. 36) of the right-angled triangle having for sides  $Sa$  and  $a\alpha$ . To construct it, take  $DF$  equal to  $Sa$ , draw  $FE$  parallel and

\* Dr. E. Deville, *Photographic Surveying*.

equal to  $a\alpha$ , join  $DE$  and produce to the scale of degrees and minutes  $BC$ . This construction is facilitated by the lines previously drawn on the board. With a pair of compasses, take the distance from  $\alpha$  to the principal line, carry it from  $P$  (fig. 35) in the direction of  $PD'$ , and from the point so obtained take the distance to the arc  $ML$ , measuring it in the direction of the radii marked on the board: this is the distance of  $PF$  (fig. 36). Then, with the compasses, carry  $a\alpha$  to  $FE$ , which is done by means of the parallel lines  $MN$  of fig. 35. The construction is now completed as already explained.

## 16. Contours

When a sufficient number of points have been plotted and marked on the plan, together with their elevations, the topographer places the views before him, and, using the points as a guide, endeavours to draw the contours, following the inequalities of the surface as shown on the views. Having the photographs from different stations constantly before him, he is able to make comparisons and to determine the true shape of the features much more accurately than if dependent on views from one station only, and can accordingly sketch in his contours to represent the topography much more accurately than he could otherwise.

Instead of drawing the contours on the plan at once, the draftsman may commence by sketching them on a photograph in the same way as on the plan. The points are already marked on the view, and the elevation may be transferred from the plan or from the original lists. In this way he is able to follow closely the shape of the *terrene*, and the contours on the views will be of assistance later when drawing the contours on the plan. If the work is new to him, the sketching on the views will at least give him a better idea of the topography and of the significance of contour lines.

In obtaining a correct representation of the various topographical features, a knowledge of geology and of the forms produced by different agencies is of great assistance. Each agency acts in a manner peculiar to itself and produces certain characteristic forms. The surveyor, recognizing these typical forms and knowing the process of their formation, is able to draw his contours in such a way as to give a much more natural and lifelike appearance to his plan. When information is incomplete and he is compelled to resort to sketching for some of the smaller valleys, a knowledge of the geological influences by which they have been formed is often a very great help in determining the probable shape.

The most tedious and tiresome part of the work is plotting the points and drawing the contours. The office work requires at least twice as long as the field work. However, the time required for the field work, which is the more expensive, is less than if any other method of survey were employed, and consequently, delays due to adverse conditions are reduced to a minimum. The office work is carried on by a small staff under favourable conditions and is not so subject to unexpected interruptions.

## 17. Precision of Survey

As in the case of other topographic surveys, the accuracy of a photographic survey depends on the precision of the control and the scale of the plan. After this it depends on the number of the camera stations and the number of points plotted. When the points are located by intersections, as is usually the case, the precision is that of a good plane-table survey, but with the advantage that many more points are plotted and the contouring is done by the surveyor in the office with views from different stations constantly before him, enabling him not only to study the country from different view points, but also to obtain more points if required. In a plane-table survey this simultaneous comparison is entirely lacking, and the topography as seen from one station may appear to differ materially when seen from another.

When fewer stations are taken and other less accurate methods are used to supplement that of intersections, the results are less precise, but it must be remembered that under similar circumstances the ordinary topographer would have to rely on sketching. Consequently the results furnished by photography are the more accurate.

Another strong point in favour of the camera is the rapidity with which the work at any station may be completed. In mountainous country where much of the day must be devoted to the ascent and descent, in cold windy weather, or when storms are threatening, comparatively little time can be spent on the peaks. In such cases the topographer must block his tripod securely with rocks and work hurriedly to complete his observations. Little difficulty is experienced in keeping the instruments steady in almost any wind, and the work may be completed in about two hours, or even less in an emergency, no matter how rough the country may be. With the plane table much more time is required, it is more difficult to keep the instrument steady, and it is hard for the topographer to do good work while suffering from cold and exposure, especially after a long and fatiguing climb. Consequently, his information will not be as complete or as accurate as that given by the photographs. Moreover, if interrupted by storms or clouds, he will often have to reoccupy stations, where with the camera the work could have been completed on the first trip.

## 18. General Remarks

Different men adopt different methods of working, and the organization used by one may not be satisfactory to another. The strength of the party will be affected by many other considerations, such as the nature of the country, the number of instruments in use, the extent of the survey, etc. Consequently, the following remarks are offered as suggestions, outlining the organization of a party which has been found efficient on Canadian surveys in the Rocky mountains.

The party is composed of seven men, consisting of the surveyor, his assistant and five men, two of whom should be expert packers if packhorses are used. With two sets of instruments, the surveyor and assistant surveyor, each accompanied by two men, are free to work in different localities, the cook being left in charge of the main camp at some central point. Except on long or dangerous trips, only one man is required to accompany the surveyor when climbing. This however is the minimum strength of the party. In a country where transportation is difficult, where the climbs are long or dangerous, or if the packhorses are not well broken and trained for their work, extra men will frequently be necessary. Even under ordinary circumstances an extra man is so often useful that it may be considered advisable to include him permanently in the party.

Owing to the nature of the country to which photographic surveys are applicable, it is probable that the demand for this work will always be rather limited. There are very large mountainous areas in Alberta and British Columbia which can be satisfactorily mapped in this way and other less broken areas, some partially timbered, in the foot-hills and elsewhere, which may be mapped by the camera alone or by the camera used in conjunction with other methods. This class of country will not develop suddenly but slowly and gradually, and there will be a constant demand for topographic maps for administrative and other purposes, so that ultimately it will all have to be surveyed.

So far, the work has been confined chiefly to Government surveys of large areas on comparatively small scales, but surveys of small areas on large scales are frequently required for various purposes such as reservoir sites, mineral claims, etc. Where the country is broken or rolling, and suitable camera stations can be found, almost any degree of accuracy can be obtained, and the topography mapped quickly and accurately with a surprising amount of detail. Another purpose for which the system is eminently suitable is that of mapping the banks of rivers running through deep valleys such as are often found in the western provinces. By making a control traverse of one or both banks and taking a few views at some of the stations, the river banks and small side valleys could be

accurately plotted, and, by means of the perspectometer, the river itself could be laid down with almost as great a degree of precision and with greater detail than if actually traversed.

These instances are mentioned only as illustrations. No doubt there are many other purposes for which photographic methods will be found useful and economical, and, as the system becomes better known and more popular, its field of usefulness will become greatly extended.

## 19. List of the Principal Photographic Surveys Made in Canada

BY THE TOPOGRAPHICAL SURVEY OF CANADA, DEPARTMENT OF THE INTERIOR

Locality	Area surveyed in square miles	Year	Surveyor
Main range of the Rocky mountains adjacent to the Canadian Pacific railway.....	2,500	1886-92	J. J. McArthur
Columbia valley from Revelstoke to Arrowhead, B.C.	600	1897	J. J. McArthur
Alberta foot-hills southwest of Calgary, Alta.....	2,000	1896-9	A. O. Wheeler
Crowsnest coal area near Crowsnest Pass, B.C.....	550	1900	A. O. Wheeler
Selkirk mountains adjacent to the Canadian Pacific railway, from Beavermouth to Revelstoke, B.C..	1,100	1901-2	A. O. Wheeler
Rocky mountains adjacent to the Canadian Pacific railway, from Mount Castle to Beavermouth, B.C.	2,200	1903-6	{A. O. Wheeler M. P. Bridgland
Rocky mountains, Robson district, north of Yellowhead pass.....	1,100	1911	A. O. Wheeler
Crowsnest forest reserve, southwestern Alberta.....	1,500	1913-4	M. P. Bridgland
British Columbia-Alberta boundary.....	5,100	1913- 1923	{A. O. Wheeler A. J. Campbell
Jasper park adjacent to the Canadian National railways.....	900	1915	M. P. Bridgland
Bow river and Clearwater forest reserves, Alta.....	2,000	1917-20	{M. P. Bridgland L. E. Harris
Pitt Lake basin, B.C.....	250	1921	{M. P. Bridgland L. E. Harris
South part of Kootenay park and vicinity.....	1,150	1922-23	

BY THE GEOLOGICAL SURVEY, DEPARTMENT OF MINES

Kananaskis, B. C. and Alta.....	1,500	1916	D. A. Nichols
Hazelton, B.C.....	225	1917	F. S. Falconer
Britannia, B.C.....	90	1918-9	K. G. Chipman
North Thompson river, B.C.....	800	1918-21	D. A. Nichols
Coquihalla river, B.C.....	275	1918	F. S. Falconer
Cariboo, B.C.....	260	1920	D. A. Nichols
Kitsault river, B.C.....	40	1920	W. H. Miller
Kootenay valley, B.C.....	250	1921	R. Bartlett
Mountain park, Alta.....	250	1921	W. H. Miller
Kootenay Valley, B.C.....	140	1922	R. Bartlett
Kokanee Mountains, B.C.....	150	1923	A. C. T. Sheppard
Babine, B.C.....	195	1923	W. H. Miller
Reconnaissance surveys.....	9,000	1904-15	

BY THE INTERNATIONAL BOUNDARY SURVEYS AND THE GEODETIC SURVEY,  
DEPARTMENT OF THE INTERIOR

Locality	Area surveyed in square miles	Year	Surveyor
British Columbia-Alaska boundary.....	5,000	1893-1913	Dr. W. F. King
Southern boundary of British Columbia.....	1,200	1903-5	J. J. McArthur
Yukon-Alaska boundary (141st meridian).....	1,000	1907-13	J. D. Craig
Thirtyone Mile Lake watershed, Que.....	200	1913-4, 20	D. H. Nelles

BY THE BRITISH COLUMBIA GOVERNMENT

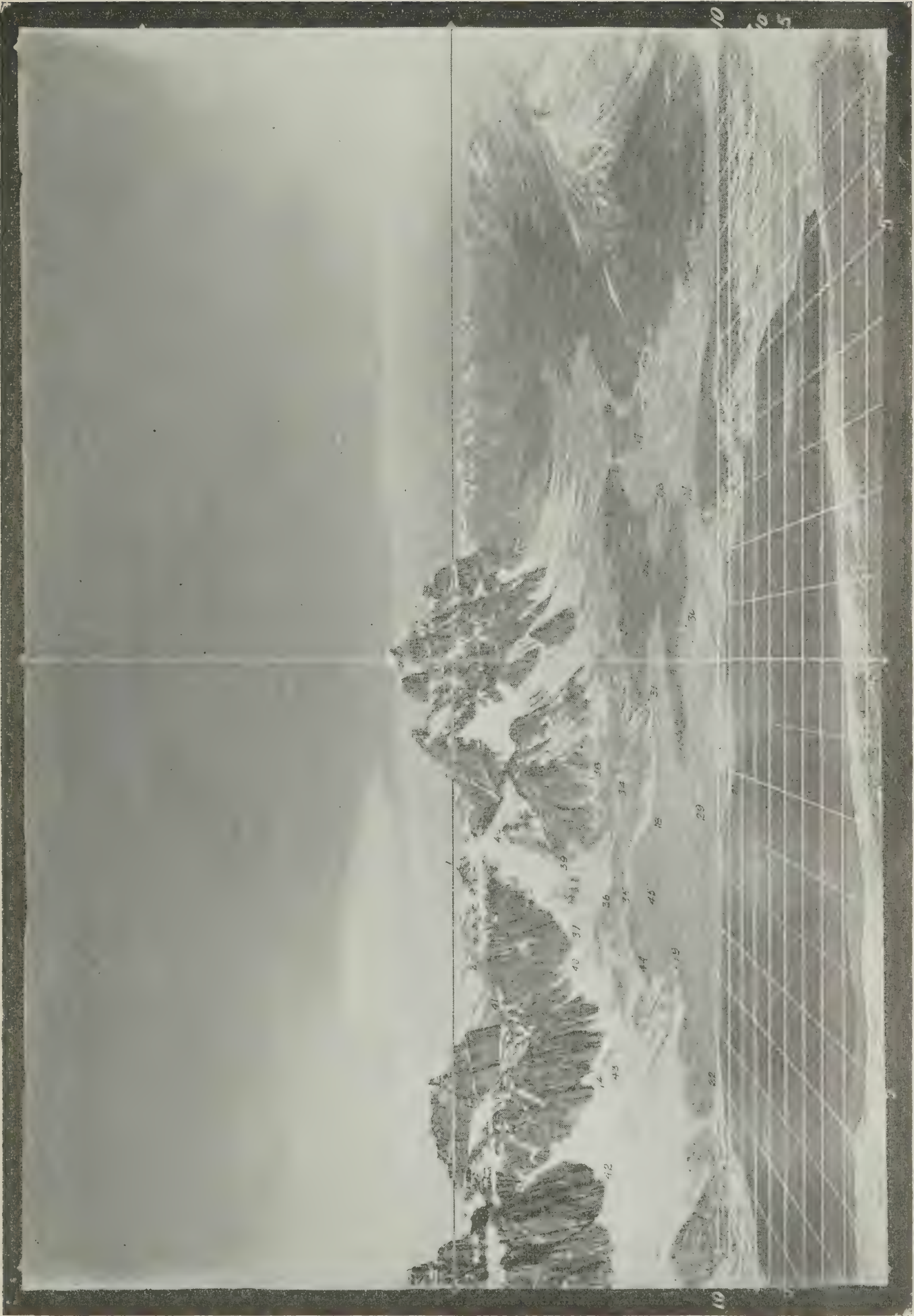
Rocky mountains, Banff-Windermere road from Vermilion pass to the junction of Kootenay and Vermilion rivers.....	500	1913	R. D. McCaw
Okanagan Lake district, B.C.....	3,300	1914-9	R. D. McCaw
Harris Creek watershed, B.C.....	175	1919	R. D. McCaw
Lower Similkameen valley, B.C.....	650	1919-20	{ R. D. McCaw G. J. Jackson
Upper Nicola valley, B.C.....	1,100	1920-22	R. D. McCaw
Okanagan watershed, B.C.....	400	1921	G. J. Jackson
Similkameen valley, B.C.....	400	1922	G. J. Jackson



View No. 1—From Station No. 10



View No. 2—From Station No. 11



View No. 3—From Station No. 11



View No. 4—From Station No. 16



View No. 5—From Station No. 15







# NOTE

In order to avoid confusion, only a few of the points used in contouring have been shown. An examination of the notes will show that as many points as desired can be identified and plotted.

N716  
1000'

Mt. Magnetic  
1010'



## REFERENCE

Camera Station and Points fixed by Triangulation  
Glaciers  
Tides

Mt. Gekko  
10254'

Bestion Pk.  
8000'

N711 Mt. Cithereos  
8454'

N719  
8439'  
Mt. Maccarib

Old Horn Mtn.  
9179'

N714  
7972'  
Surprise Pt.

Mt. Fraser  
10726'

Thunderbolt Pt.  
8725'  
N713

## MAP OF THE VICINITY OF AMETHYST LAKES, ALBERTA to illustrate the methods of PHOTOGRAPHIC SURVEYING

Scale: 40000  
Chains of 100 0 10 20 30 40 Miles  
Kilometres 0 10 20 30 40 Kilometres  
Contour Interval 500 Feet  
(Datum is mean sea level)



Gov. Doc. Canada. Topographical Survey  
Can Bulletin No. 56. Bridgland, D.L.S.,  
T Photographic Surveying.

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